Supplement of Biogeosciences, 22, 2935–2958, 2025
https://doi.org/10.5194/bg-22-2935-2025-supplement

Biogeosciences
Open Access

Supplement of

Altered seasonal sensitivity of net ecosystem exchange to controls driven by nutrient balances in a semi-arid savanna

Laura Nadolski et al.

Correspondence to: Laura Nadolski (lnadolski@bgc-jena.mpg.de)

Text S1: Preliminary analysis with half-hourly data – daily, multiday and seasonal signal

For a preliminary analysis we used half-hourly measured values (gap-filled values were removed) of day- and nighttime NEE and environmental variables to extract the daily, multiday and seasonal signal of the timeseries. We gap-filled the timeseries with the igapfill function from the rssa-package (Golyandina and Korobeynikov, 2014). The recommended window length is L = N/2.5 (Mahecha et al., 2007), but it requires extensive computational resources. It was not possible to conduct this with a reasonable amount of memory on the institute-internal high-performance slurm cluster. Gap-filling the complete time series of almost 10 years took more than six days. Therefore, we artificially diminished the window length to L=4000. We did this for gap-filling the complete NEE timeseries. To find a good trade-off between required computational resources and quality of gap-filling we conducted a sensitivity analysis with a three-year time series with R. After the sensitivity analysis, the window length L=10000 was chosen as a reasonable length for a good trade-off for a 3-year time period.

To find out how the total length n of the time series affects the gap-filling result, we then compared the respective part of the gap-filled 10-year time series with the 3-year gap-filled timeseries from the sensitivity analysis with the same window length (L=4000). We mostly found marginal differences (< 0.00), except for 3 months in the beginning and the end of the 3-year comparison period. To reduce these edge effects, we finally chose to artificially prolong the time slices for the analysis by 3 months and then cut out the actual 3-year time period out of those gap-filled values.

We start the analysis at 01.01.2016 in respect to the data availability of all variables at all three towers, to provide the same time series length for all. For the first time slice (01.1.2016-31.12.2018) the time period of October, November and December 2017 were put in front of the beginning as artificial prolongation and in the end of the slice a natural prolongation of the months 01.01.2019 – 31.03.2019 from the original time series. For the second time slice the four-year period of 01.01.2019-31.12.2022 was chosen. The gap-filling was conducted in the same way. Margins were added to reduce edge effects. The margins are 1.10.2018 00:00 - 31.12.2018 23:30 and 01.01.2023 00:00 - 31.03.2023 23:30 and are cut off after the gap-filling procedure.

For the SSA we adapted the window length according to the signal we want to retrieve (Biriukova et al., 2021). Golyandina and Zhigaljavsky (2013) recommend it to be an “integer multiple of P, i.e. L= nxP”. The grouping was done according to the following bins: 2h-1.3 days for the daily signal, multiday 2.7 -21.3 days for the multiday signal and 15 – 366 days for the seasonal signal. We chose window lengths of 2 times the upper bin threshold of the respective frequency bin from the signal we want to retract: 2 years (35136 half-hourly timesteps) for the seasonal signal, 6 weeks (2016 timesteps) for the multiday signal, 2.6 days (125 timesteps). We then substracted the reconstructed signal from the gap-filled timeseries before continuing with the next timescale iteratively.

The results show that the contribution of the multiday signal in explaining overall variability is marginal for most variables (Fig. S1).

By identifying the drivers of NEE on the daily scale with MI_{sync} and MI_{max} we found that as hypothesized the radiation components SWDR and PAR were the most important in explaining NEE variations (Fig. S2). We further see no substantial differences between the treatments.

Text S2: Gapfilling of daily datasets with Singular Spectrum Analysis

The gap-filling of the daily-resolution dataset was conducted in R as described above. The margins added to the daily dataset are: 10.2017 - 12.2017 and 01.2023-03.2023. They were cut off after the gap-filling procedure that was executed on the slurm cluster. For the GCC measures the margins are: 10.2015 - 12.2015 and 01.2023-03.2023; for NDVI the margins are 10.2015 - 12.2015 and 01.2021 - 03.202. As a window length of L = N/2.5 is recommended (Mahecha et al., 2007), we used for the 7-years daily data (2557 datapoints) a window length of 1000.

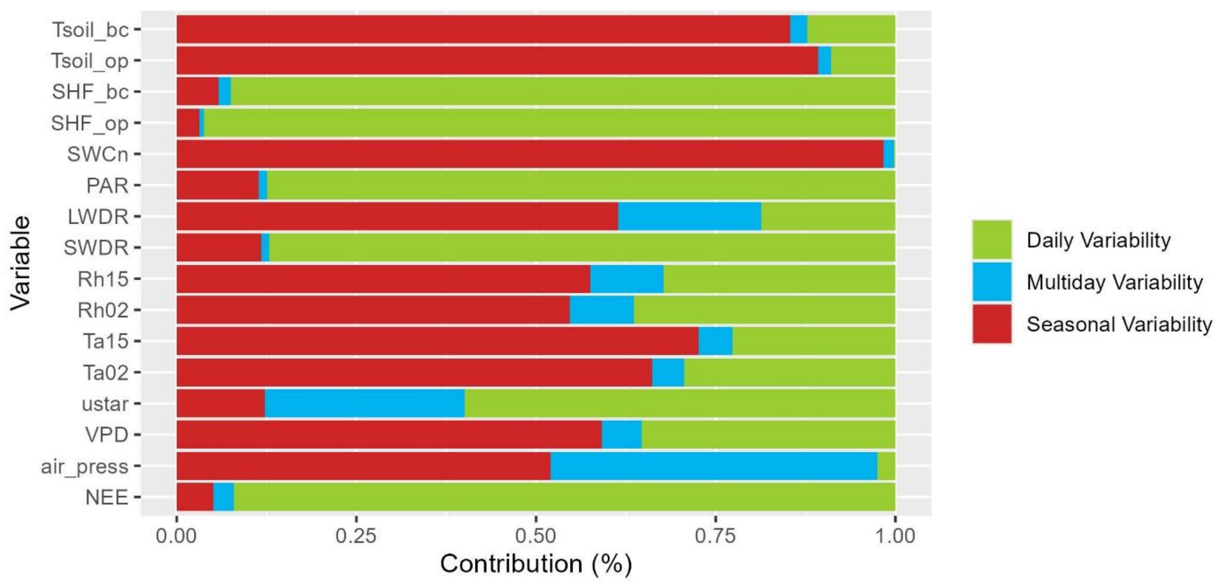

Figure S1: Relative (%) contribution of daily, multiday and seasonal variability to overall explained variability at the control plot (CT).

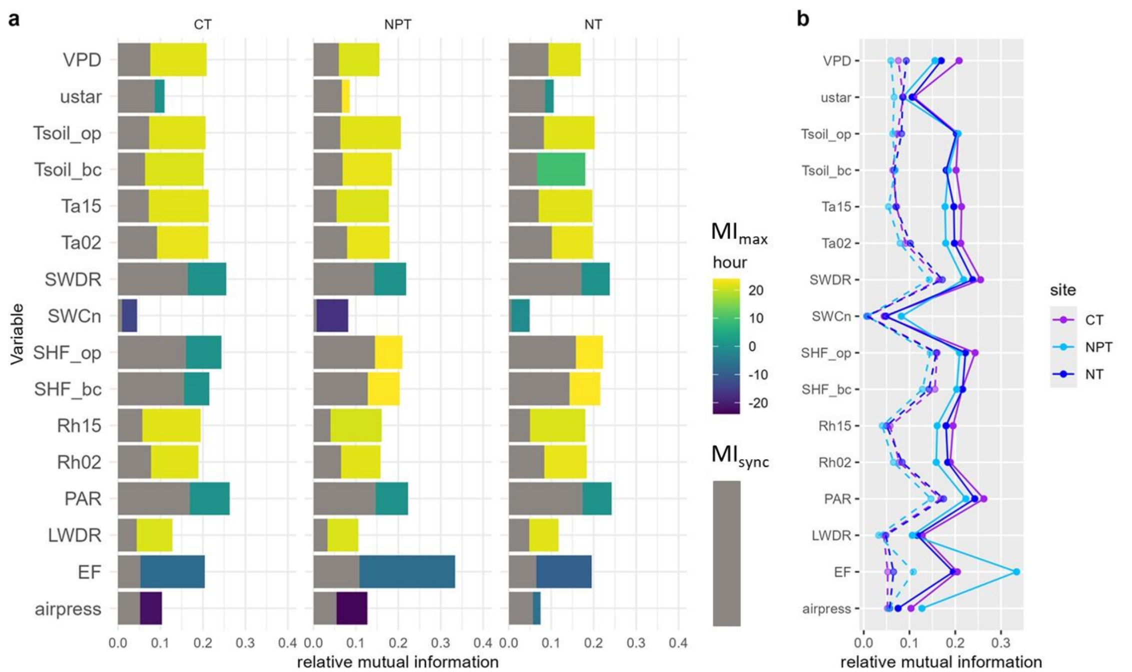

Figure S2: a. synchronous (MI_{sync}, grey) and maximum mutual information (MI_{max}, colours) at the control site (CT), the nitrogen fertilized site (NT) and the nitrogen and phosphorus fertilized site (NPT) at the daily scale. The colour scale indicates the day when MI_{max} occurs; with positive values indicating that the variable leads net ecosystem exchange (NEE) and vice versa. b: MI_{sync} (dotted lines) and MI_{max} (solid lines) values at the three sites.

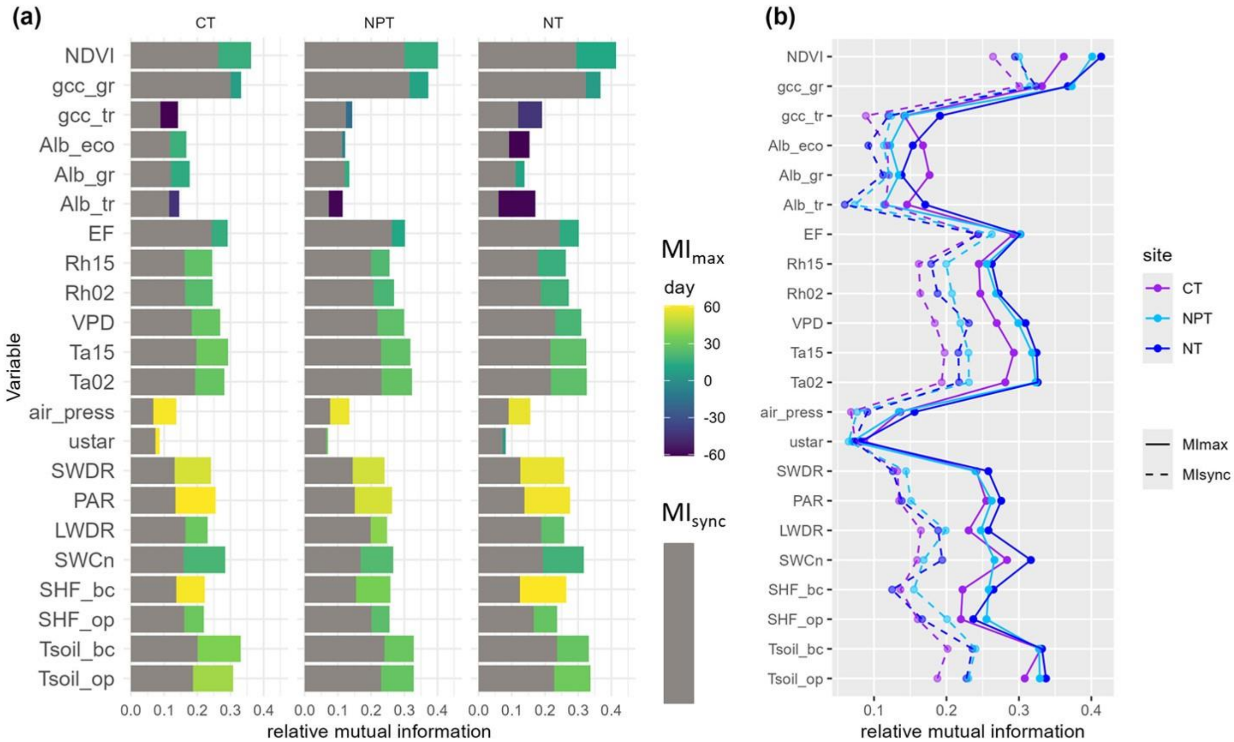

Figure S3: a. synchronous (MI_{sync}, grey) and maximum mutual information (MI_{max}, colours) at the control site (CT), the nitrogen fertilized site (NT) and the nitrogen and phosphorus fertilized site (NPT) at the seasonal scale. The colour scale indicates the day when MI_{max} occurs; with positive values indicating that the variable leads net ecosystem exchange (NEE) and vice versa. b: MI_{sync} (dotted lines) and MI_{max} (solid lines) values at the three sites.

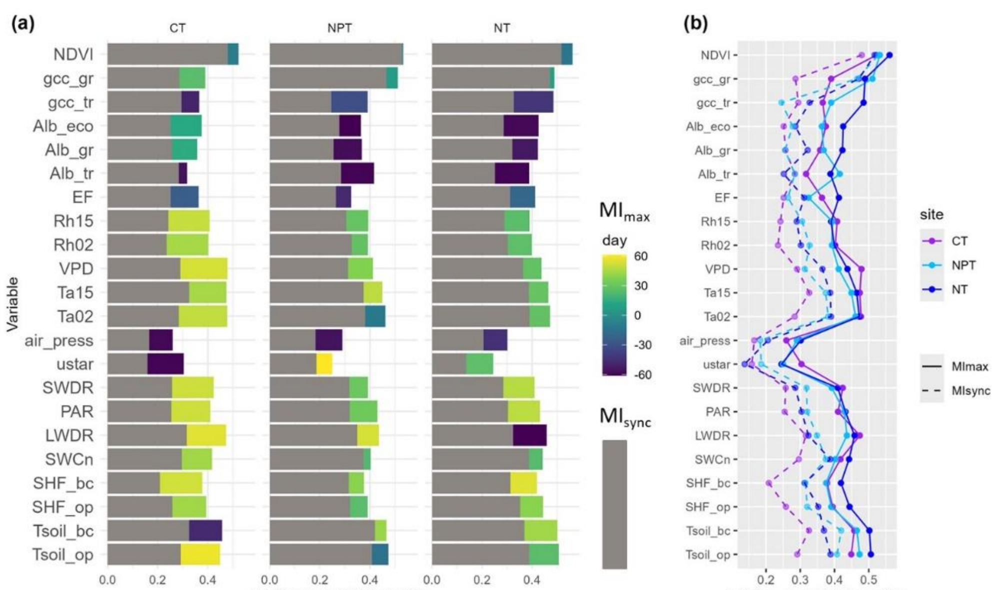

Figure S4: a. synchronous (MI_{sync}, grey) and maximum mutual information (MI_{max}, colours) at the control site (CT), the nitrogen fertilized site (NT) and the nitrogen and phosphorus fertilized site (NPT) at the seasonal scale one year after fertilization (April 2016-March 2017). The colour scale indicates the day when MI_{max} occurs; with positive values indicating

that the variable leads net ecosystem exchange (NEE) and vice versa. b. MI_{sync} (dotted lines) and MI_{max} (solid lines) values at the three sites.

a)

variable	**MI_{sync}**	**MI_{max}**	**day**
Alb_eco	0.11772876	0.16750376	17
Alb_gr	0.12047719	0.17661187	14
Alb_tr	0.11564405	0.14554554	-44
EF	0.24374901	0.2921867	15
gcc_gr	0.30061542	0.33181592	7
gcc_tr	0.08867581	0.14172762	-61
air_press	0.06816683	0.13623154	60
LWDR	0.16465547	0.23070741	31
PAR	0.13451337	0.25499359	61
Rh02	0.16379168	0.24675816	24
Rh15	0.16168878	0.24468166	27
SHF_bc	0.13647615	0.22220978	60
SHF_op	0.16026412	0.21992901	31
SWCn	0.15943073	0.28359844	20
SWDR	0.13222293	0.24139464	53
Ta02	0.19334531	0.28116365	29
Ta15	0.19748104	0.29296028	31
Tsoil_bc	0.2016078	0.3302836	37
Tsoil_op	0.18743947	0.30804474	43
ustar	0.07405485	0.08627703	61
VPD	0.18392214	0.26942703	29
NDVI	0.26423444	0.36199501	16

b)

variable	**MI_{sync}**	**MI_{max}**	**day**
Alb_eco	0.09209015	0.15353787	-61
Alb_gr	0.1123587	0.13791383	10
Alb_tr	0.05960352	0.17065947	-60
EF	0.24383065	0.30190766	14
gcc_gr	0.32366194	0.36760555	6
gcc_tr	0.11963968	0.19104968	-43
air_press	0.09081075	0.15579189	57
LWDR	0.1885456	0.25803826	26
PAR	0.1381655	0.27559199	59
Rh02	0.18781088	0.27192317	18
Rh15	0.17884909	0.26253308	16
SHF_bc	0.1249318	0.26481665	61
SHF_op	0.16631364	0.23705208	29
SWCn	0.19410951	0.31649583	18
SWDR	0.12598611	0.25783745	57
Ta02	0.21741211	0.32593695	26
Ta15	0.21643334	0.32434894	26
Tsoil_bc	0.23596201	0.3318591	29

Tsoil_op	0.22762391	0.33736884	32
ustar	0.07268535	0.08159846	5
VPD	0.23096581	0.30914403	20
NDVI	0.29455806	0.41356506	12

c)

variable	**MI_{sync}**	**MI_{max}**	**day**
Alb_eco	0.11342472	0.12228515	-6
Alb_gr	0.12082653	0.13412669	15
Alb_tr	0.07328528	0.11396369	-60
EF	0.26262279	0.30143873	12
gcc_gr	0.31523177	0.3729792	10
gcc_tr	0.12375608	0.14285954	-16
air_press	0.07673951	0.13422675	58
LWDR	0.19890105	0.24743235	39
PAR	0.15088525	0.26245326	53
Rh02	0.2076121	0.26856807	20
Rh15	0.19947535	0.25546004	22
SHF_bc	0.15501874	0.25824679	35
SHF_op	0.2008617	0.25528881	25
SWCn	0.16857209	0.26624298	23
SWDR	0.14403219	0.24009299	52
Ta02	0.23105497	0.32297797	28
Ta15	0.2304047	0.31819103	27
Tsoil_bc	0.24014	0.32774306	30
Tsoil_op	0.23028433	0.32882794	29
ustar	0.06493692	0.06991779	31
VPD	0.21920735	0.29911951	26
NDVI	0.30036176	0.4012426	15

Table S1: Synchronous (MIsync, grey) and maximum mutual information (MImax, colours) values and leading/lagging days at the control site (CT, a), the nitrogen fertilized site (NT, b) and the nitrogen and phosphorus fertilized site (NPT, c) at the seasonal scale.