Modeling of reticular and ventral ruminal pH of dairy cows using feed and water intake and rumination behavior

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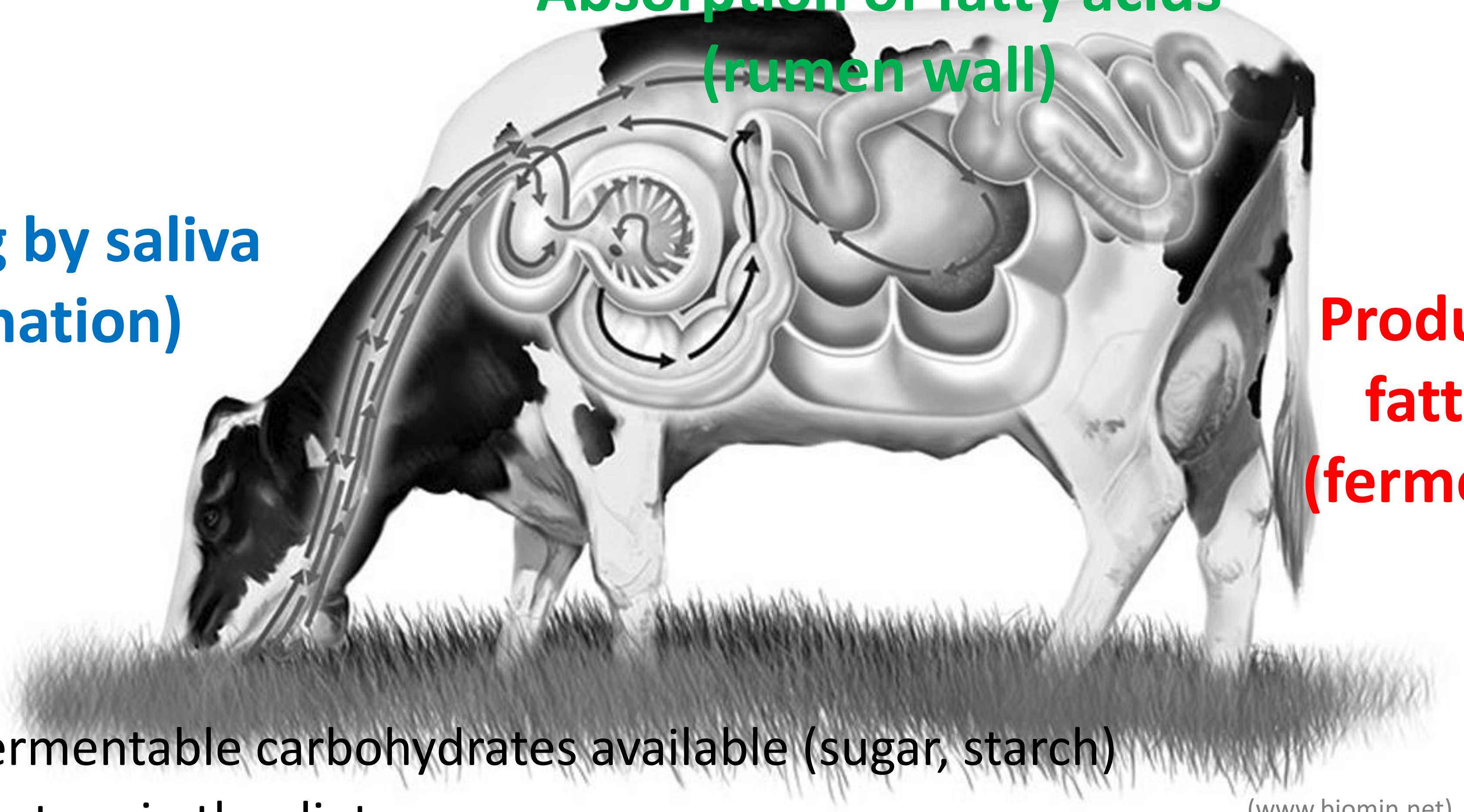
Introduction



(www.biomin.net)

- Plenty of fermentable carbohydrates available (sugar, starch)
- Lack of structure in the diet

⟶ Risk of digestive disorders ↑ (Nocek, 1997)

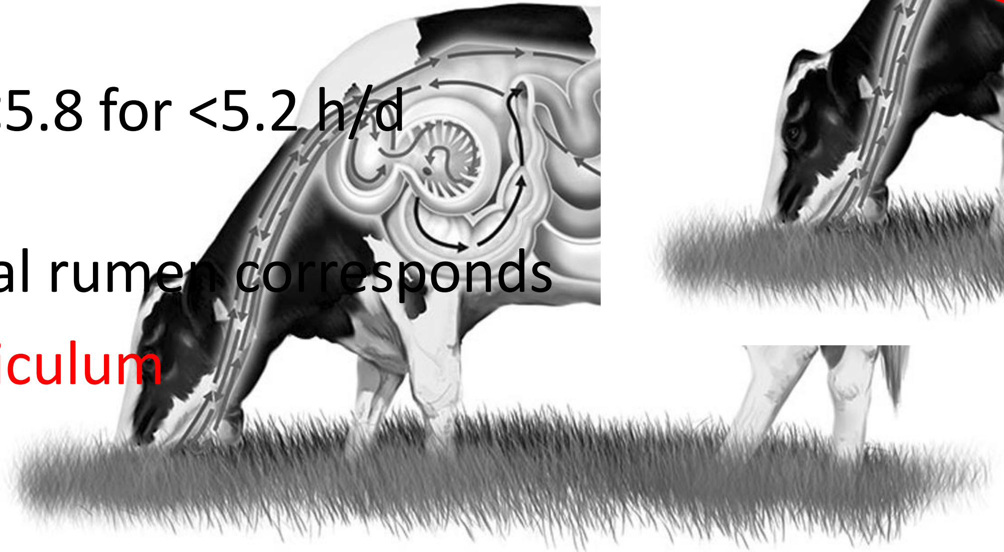
Introduction

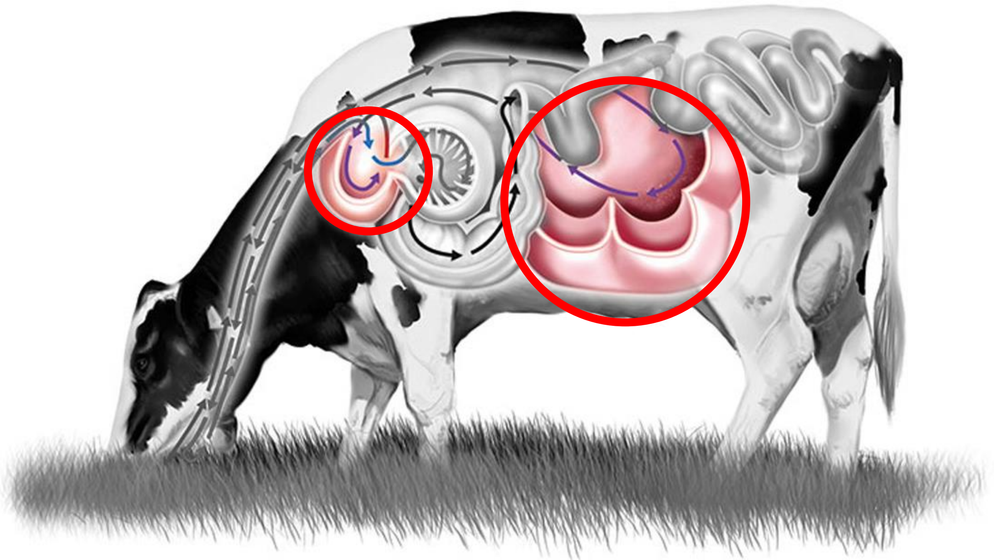
Sub-**A**cute **R**uminal **A**cidosis (SARA)

- pH as direct indicator
- Current definitions based on pH thresholds in the ventral rumen
  - $\overline{pH}$>6.2 and time pH<5.8 for <5.2 h/d

    (Zebeli et al., 2008)
- A pH of 5.8 in the ventral rumen corresponds to a pH of 6.0 in the reticulum

  (Neubauer et al., 2016)





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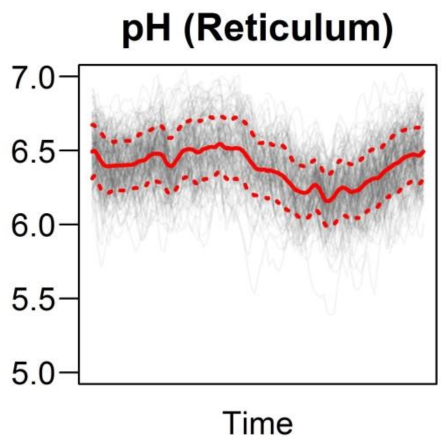
healthy ? SARA ? acute acidosis

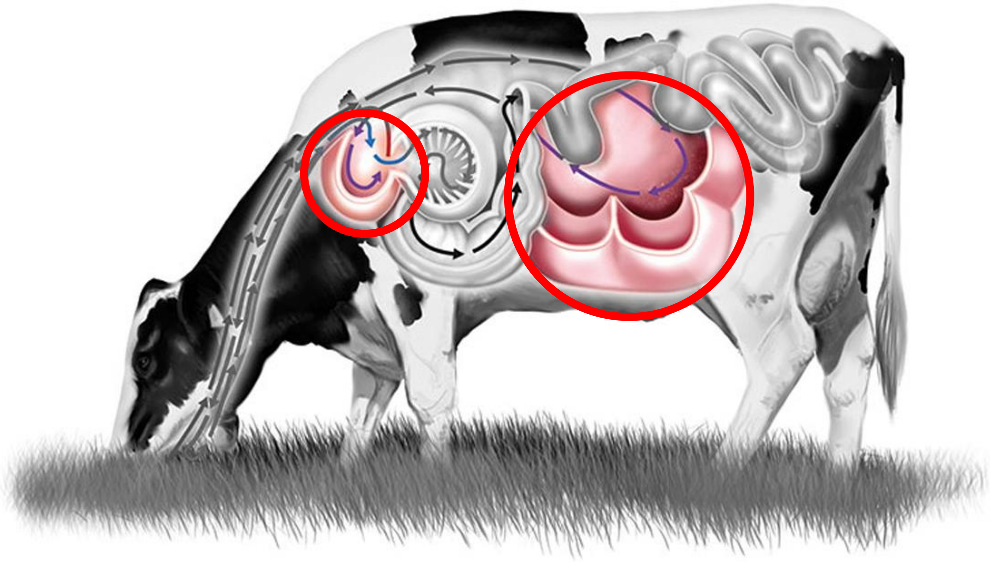
clinical symptoms

Objective

Explanation of daily pH development in the reticulum and in the ventral rumen using individual

- feed and water intake
- rumination behavior





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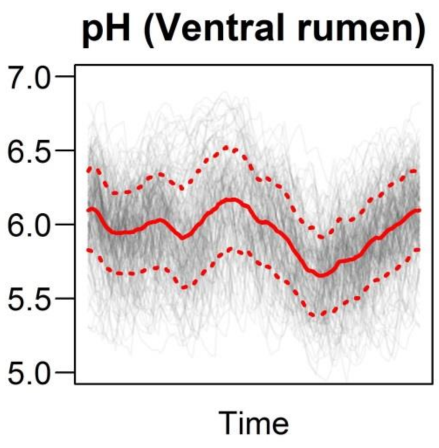
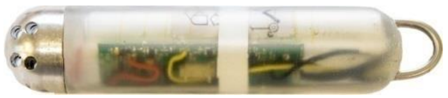


Materials and Methods

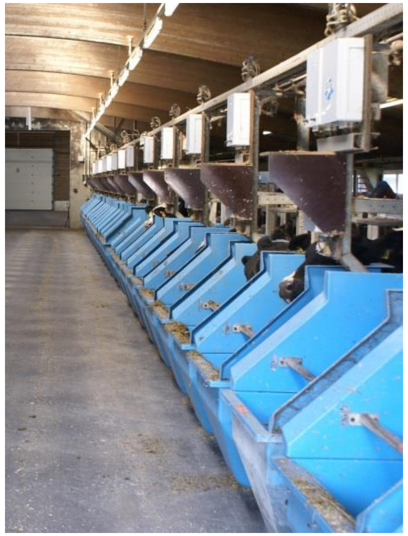
Data of 13 ruminally fistulated cows (n_{C35} = 6, n_{C60} = 7)



(www.agriexpo.online)

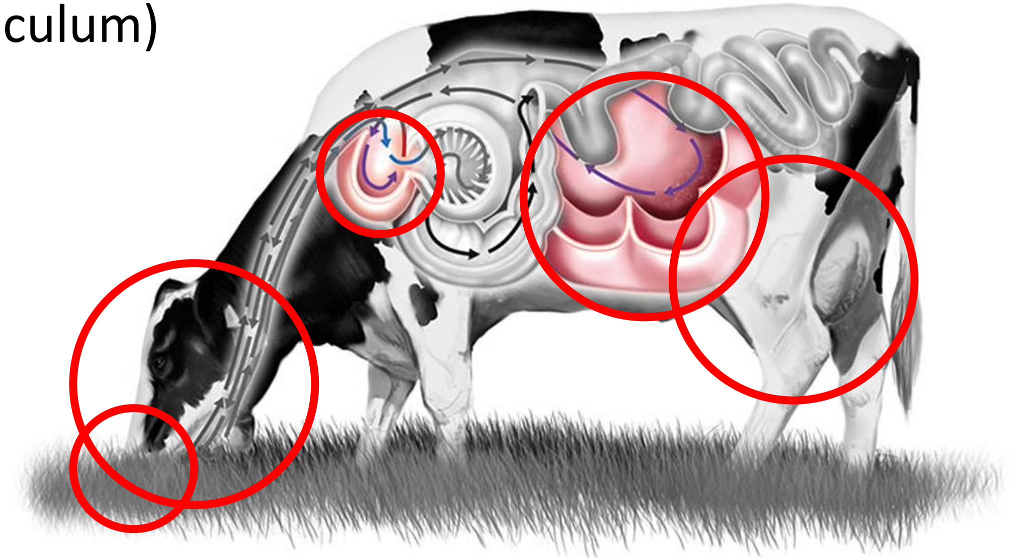
eCow bolus
(Reticulum)

Milk yield and live weight
(2 x daily)



(Bünemann, 2019)

Insentec transponder feeders
- Partial Mixed Ration (PMR)
- Concentrate
- Water



(www.biomin.net)

(Bünemann, 2019)

LRCpH Dascor logger
(Ventral rumen)

RumiWatch halter
(Rumination behavior)

(Bünemann, 2019)

Materials and Methods

Time series analysis (Shumway and Stoffer, 2016)

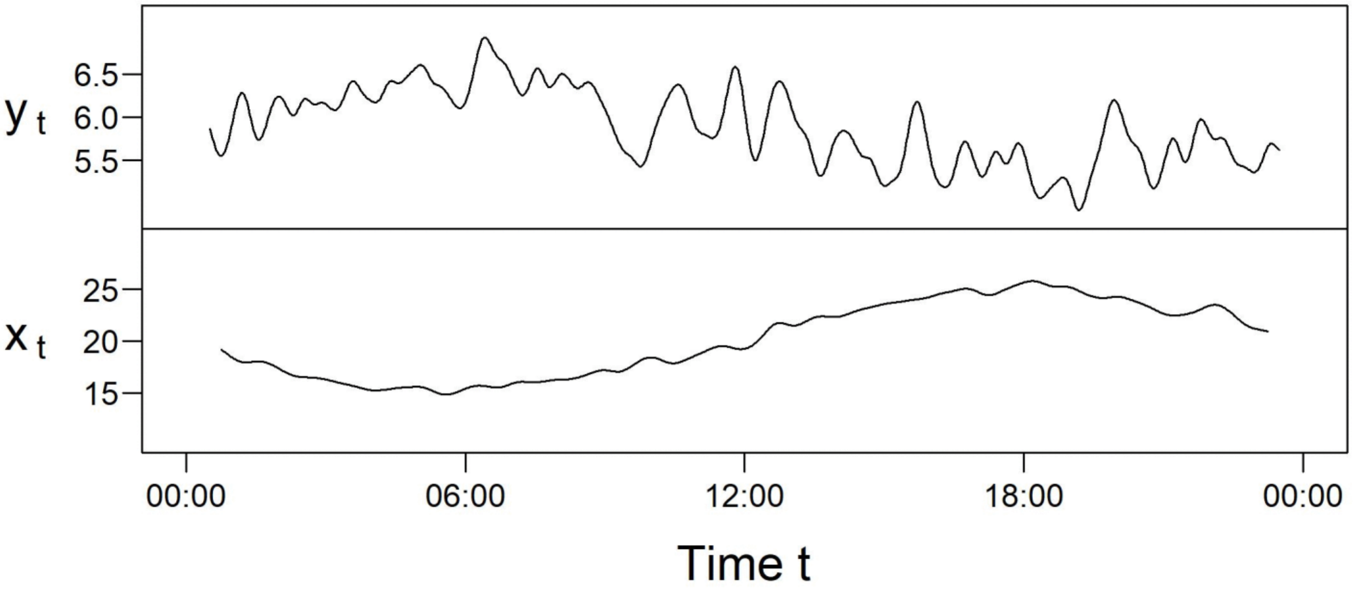
- Classical regression models in a time series context

$$y_t = \beta_0 + \beta_1 x_{t,1} + \beta_2 x_{t,2} + \cdots + \beta_k x_{t,k} + w_t$$

A simulated example: $\hat{y}_t = 7.83 - 0.10\, x_t$ (R^2 = 0.66, RMSE = 0.28)

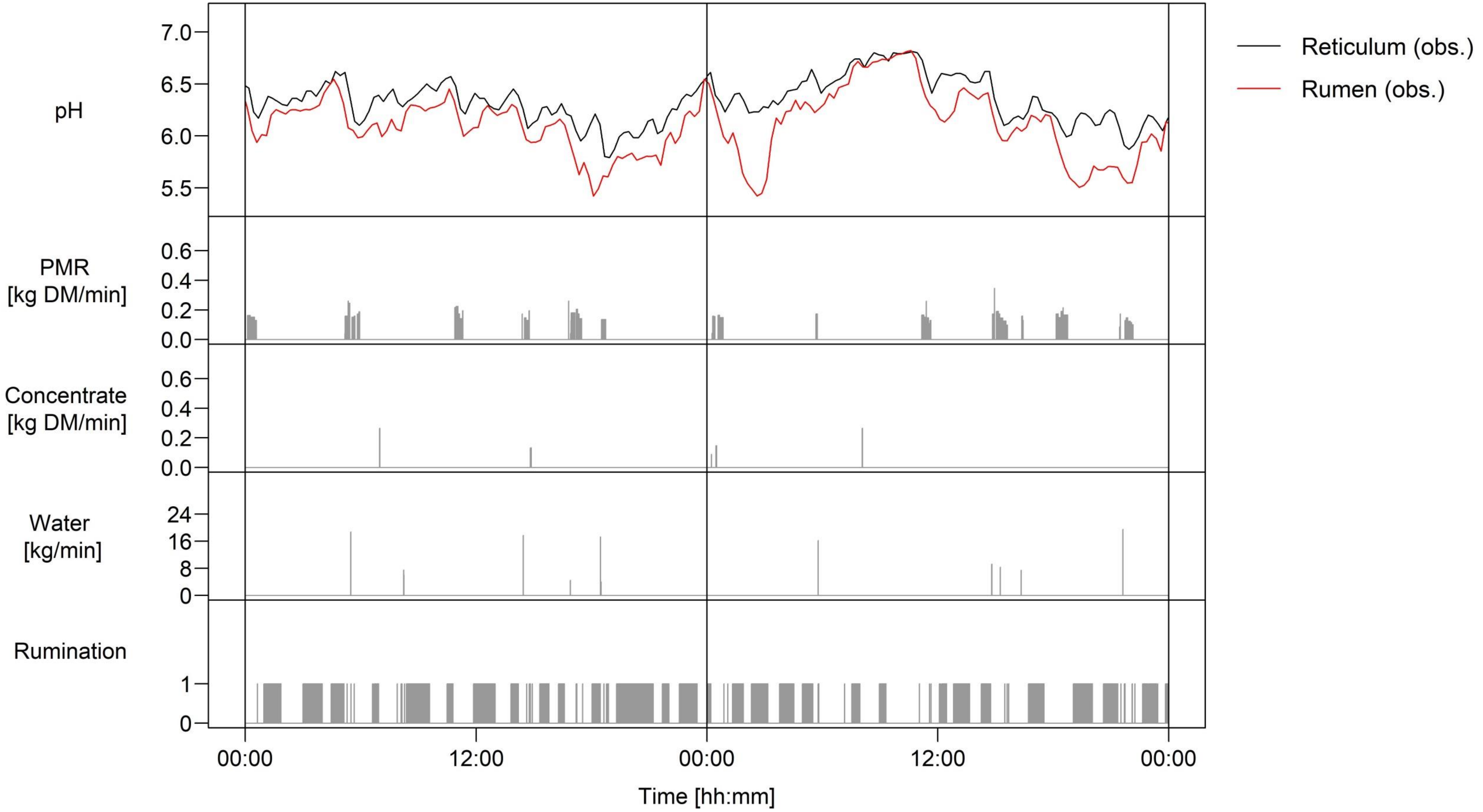
e.g. pH

e.g. intake



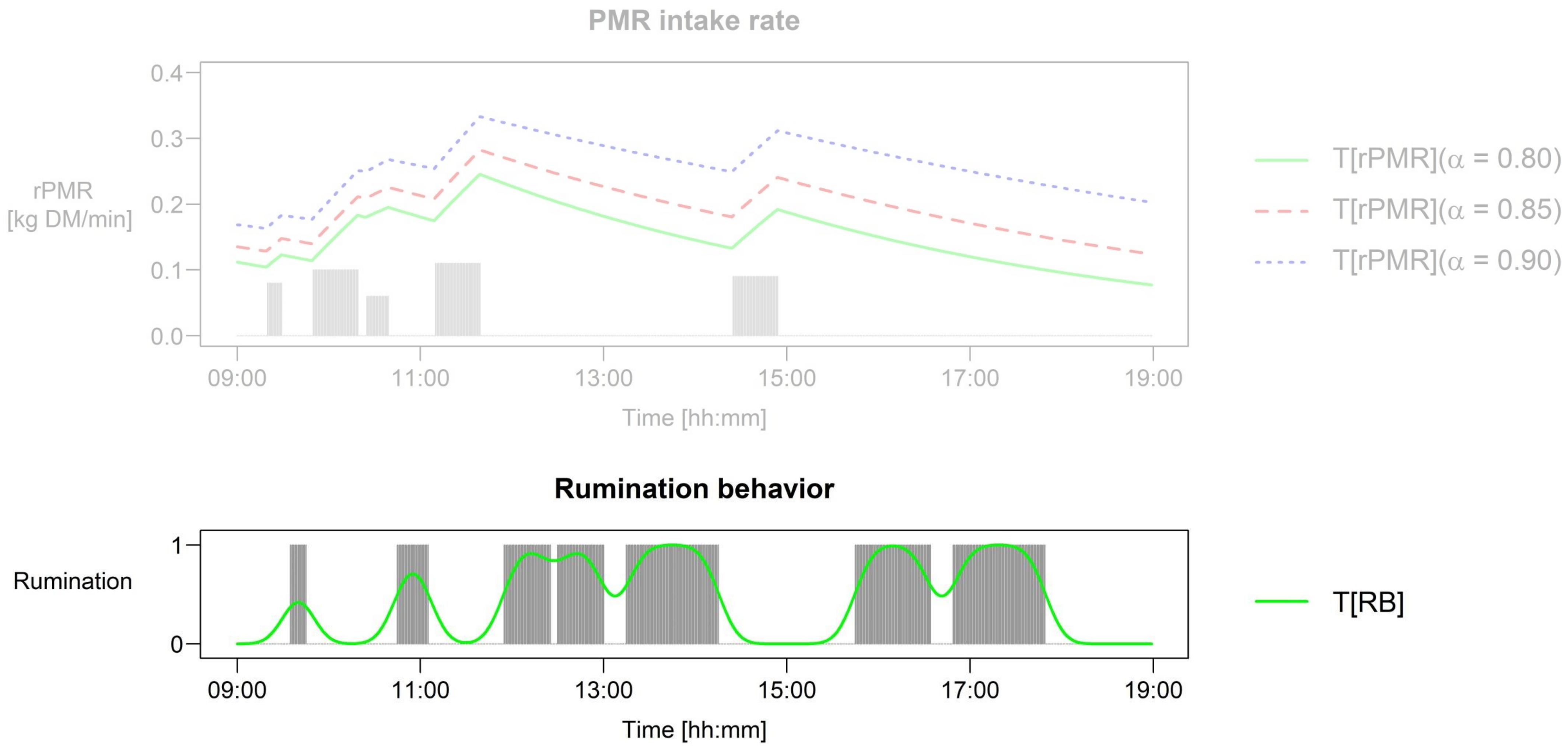
Materials and Methods

Cow A: 35 % concentrate



Materials and Methods

Signal processing: Recursive filtering
Signal processing: Moving average with a Gauss kernel



Materials and Methods

Linear mixed regression models with time series (1-minute resolution)

$$pH_{it} = \beta_0 +$$

Constant

$$\beta_1\, T[rPMR]_{it}(\alpha_{PMR}) +$$
$$\beta_2\, T[rC]_{it}(\alpha_C) +$$
$$\beta_3\, T[rW]_{it}(\alpha_W) +$$
$$\beta_4\, T[RB]_{it} +$$

Transformed ingestion and rumination behavior time series

$$\beta_5\, \Sigma PMR_{it} + \beta_6\, \Sigma C_{it} + \beta_7\, \Sigma W_{it} +$$
$$\beta_8\, DIM_{it} + \beta_9\, BW_{it} + \beta_{10}\, MY_{it} +$$

Fixed effects on a daily basis

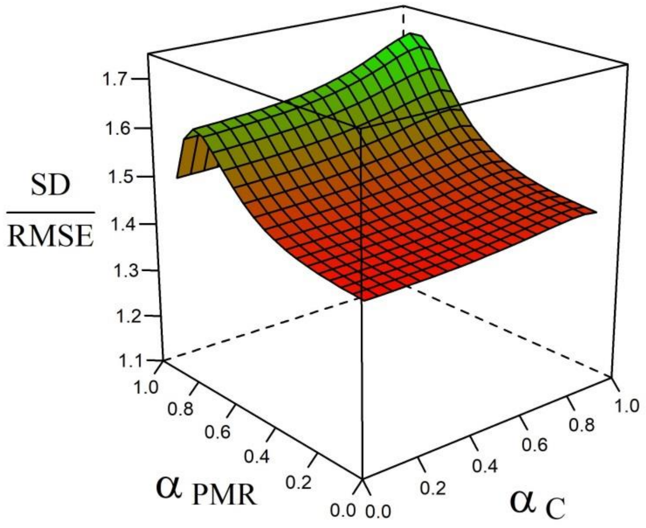
$$A_i +$$
$$w_{it}$$

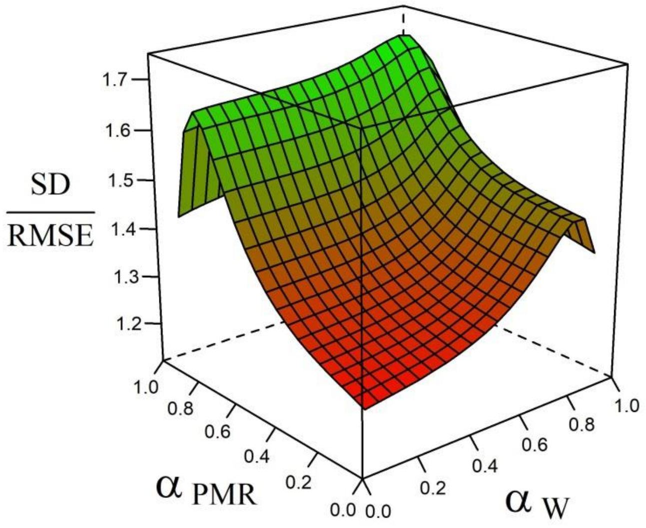
Random animal effect and random error

Materials and Methods

Linear mixed regression models with time series (1-minute resolution)

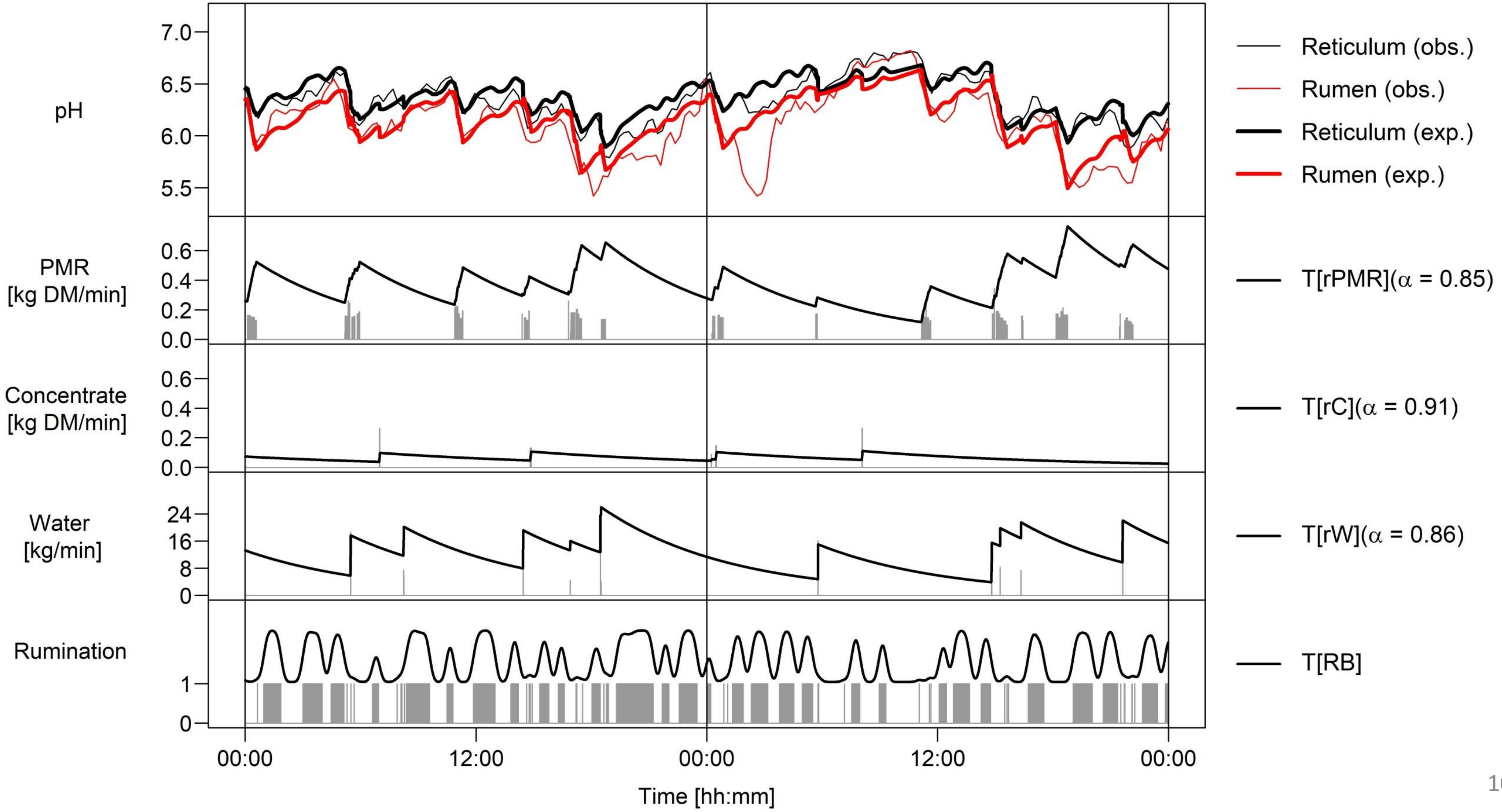
$$
\begin{aligned}
pH_{it} = \; & \beta_0 + \\
& \beta_1 \; T[rPMR]_{it}(\alpha_{PMR}) + \\
& \beta_2 \; T[rC]_{it}(\alpha_C) + \\
& \beta_3 \; T[rW]_{it}(\alpha_W) + \\
& \beta_4 \; T[RB]_{it} + \\
& \beta_5 \; \Sigma PMR_{it} + \beta_6 \; \Sigma C_{it} + \beta_7 \; \Sigma W_{it} + \\
& \beta_8 \; DIM_{it} + \beta_9 \; BW_{it} + \beta_{10} \; MY_{it} + \\
& A_i + \\
& w_{it}
\end{aligned}
$$





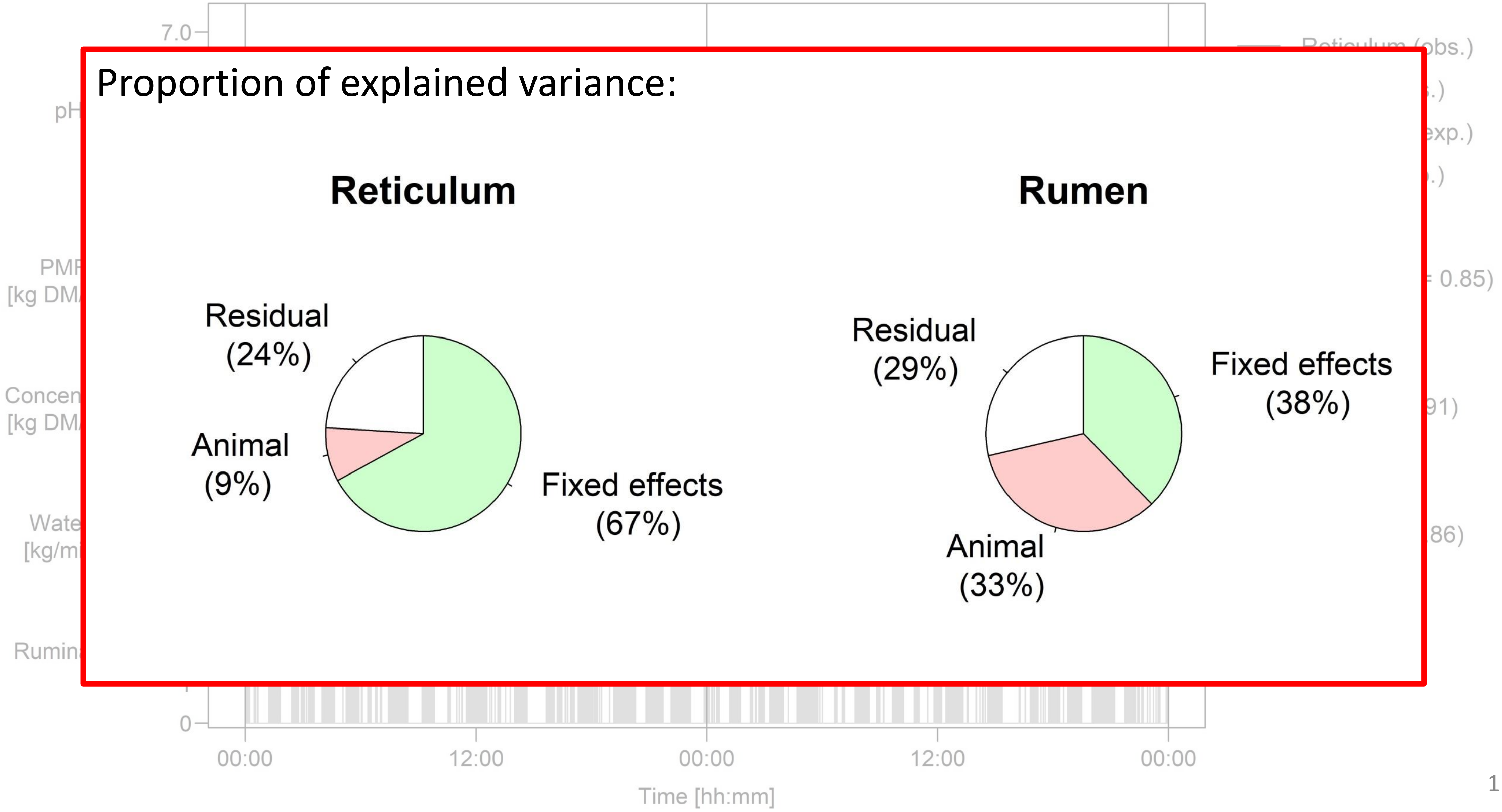
Results and Discussion

Cow A: 35 % concentrate



Results and Discussion

Cow B: 60 % concentrate



Conclusion

- Time series models are a powerful tool to investigate complex physiological relationships
  - Data preparation and signal processing are of decisive importance

- Both pH progressions are highly associated to the animal's ingestion and rumination behavior
  - Highest association to the PMR intake
  - Water intake often accompanied by PMR and concentrate intake
  - The more even the ingestion and rumination behavior distribution during the day, the lower the pH range

→ Stimulative or suppressive factors for ingestion and rumination behavior influence the pH progression, e.g. milking or feeding frequency, sickness?, …

→ Behavior can be used as an indicator for physiological processes which are difficult to measure

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CiBreed
Center for Integrated Breeding Research

Thank you for your attention!

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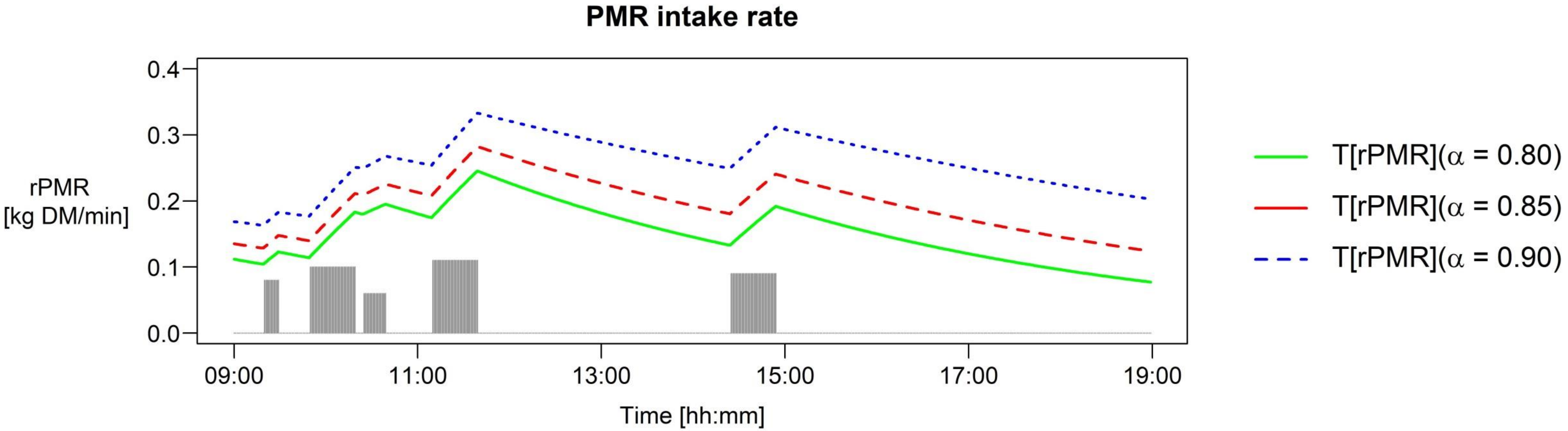
Appendix

Signal processing: Moving average with a Gauss kernel

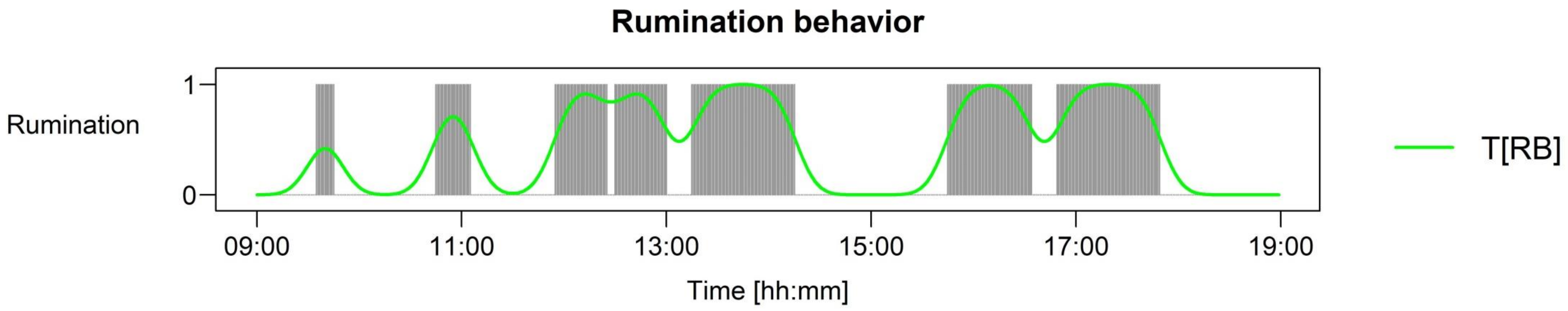


$$T[x]_t = x_t + \sqrt[60]{\alpha} \times T[x]_{t-1} \text{ with } \alpha \in (0,1)$$

$T[x]_t$	transformed time series
x_t	original time series
α	rate of change per hour

Appendix

Signal processing: Moving average with a Gauss kernel



$$T[RB]_t = \sum_{i=0}^{b} w_i \times RB_{t-\frac{w}{2}+i}$$

$T[RB]_t$	transformed rumination behavior time series
RB	original rumination behavior time series
b	window length of the symmetric Gauss kernel
w_i	weights of the symmetric Gauss kernel

Appendix

n = 13 animals, in total 145 days of continuous measurements

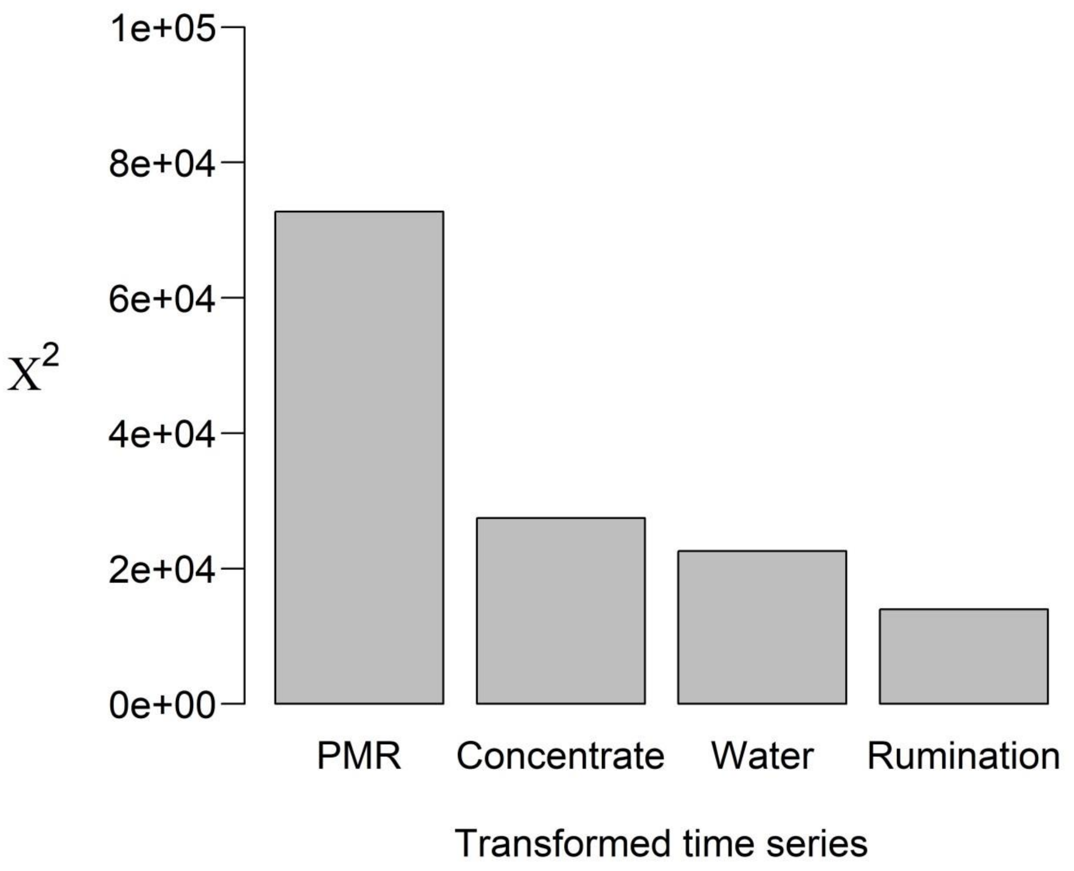
	Reticulum (eCow)				Ventral rumen (Dascor)			
	b	SE		F-value	b	SE		F-value
(Intercept)	6.87437	0.02681	***		6.40964	0.07168	***	
T(rPMR)	-0.07508	0.00025	***	86982.6	-0.13304	0.00037	***	127390.3
T(rC)	-0.09562	0.00056	***	29343.1	-0.19145	0.00102	***	35374.5
T(rW)	-0.00877	0.00006	***	23870.2	0.00340	0.00013	***	642.2
T(RB)	0.09829	0.00082	***	14439.7	0.06733	0.00147	***	2090.2
PMR	0.00930	0.00013	***	5082.2	0.02694	0.00022	***	14357.8
C	0.01093	0.00054	***	413.6	0.02982	0.00092	***	1049.6
W	0.00095	0.00003	***	1042.0	-0.00187	0.00005	***	1555.2
DIM	0.00407	0.00002	***	48739.7	0.00123	0.00003	***	1430.1
BW	-0.08243	0.00254	***	1052.6	-0.07939	0.00448	***	313.6
milk yield	0.00749	0.00011	***	4360.5	0.01433	0.00020	***	5156.8
σ (A)	0.075				0.235			
σ (r)	0.124				0.217			
R^2_m	67.02				37.79			
R^2_c	75.96				71.39			

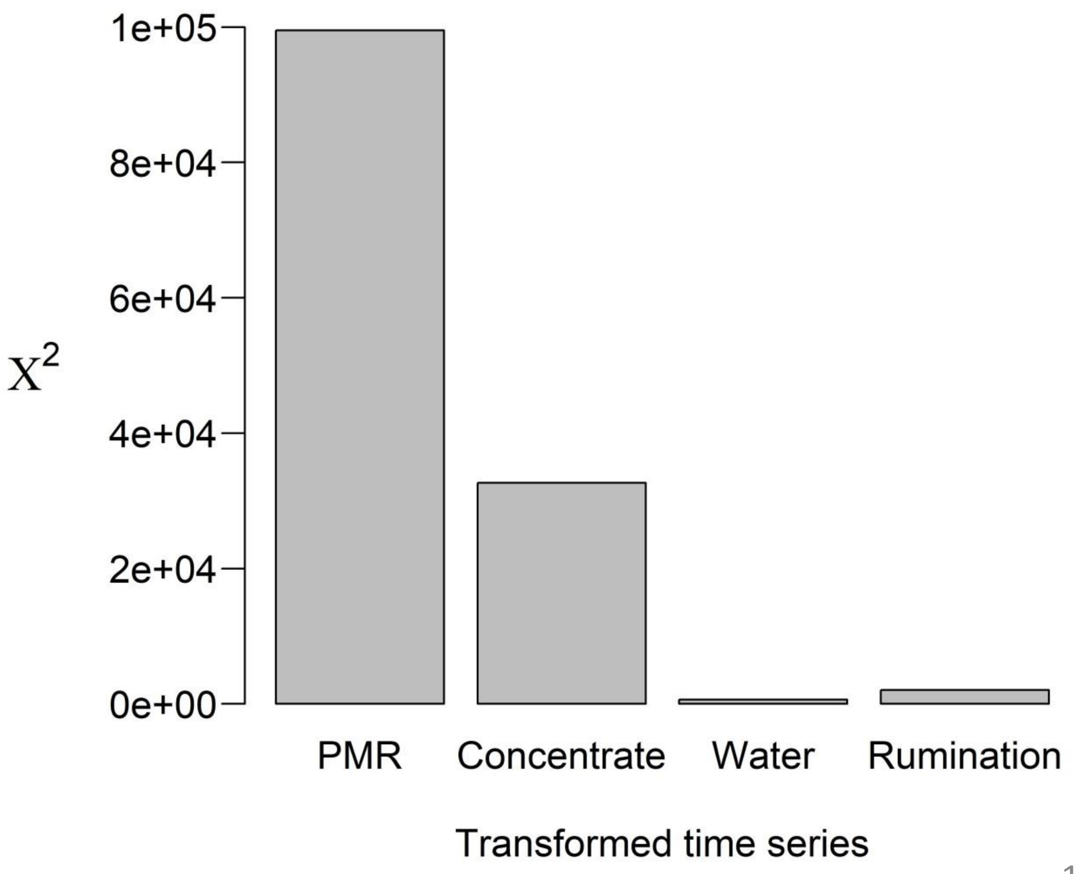
Significances with p < 0.001 are signed with `***´

Appendix

Likelihood-ratio test between full model and a reduced model by removing one variable at a time

- $\chi^2 \uparrow \leftrightarrow$ Importance $\uparrow$





Appendix

Data structure

time	pH (eCow) [pH]	pH (Dascor) [pH]	rPMR [kg DM/min]	rC [kg DM/min]	rW [kg DM/min]	Rumination
14:11:00	6.40	6.25	0	0	0	1
14:12:00	6.39	6.25	0	0	0	1
14:13:00	6.38	6.24	0	0	0	1
14:14:00	6.37	6.23	0	0	0	0
14:15:00	6.37	6.22	0.3	0	0	0
14:16:00	6.36	6.22	0.3	0	0	0
14:17:00	6.36	6.21	0.3	0	0	0
14:18:00	6.36	6.20	0.3	0	0	0
14:19:00	6.35	6.19	0.3	0	0	0
14:20:00	6.35	6.23	0.3	0	0	0
14:21:00	6.34	6.23	0	0	0	0
14:22:00	6.34	6.23	0	0	6.1	0
14:23:00	6.33	6.21	0	0.2	0	0
14:24:00	6.32	6.20	0	0.2	0	0
14:25:00	6.31	6.19	0	0.2	0	0

Appendix

Data availability

Appendix

Data availability (145 days of continuous measurements)