Biogeochemical impacts of windthrow disturbances in a mountainous Austrian karst system

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MOTIVATION

Karst systems contribute around 50% to Austria's drinking water supply. In 2007 and 2008 Middle Europe was hit by a series of storms that caused major windthrows. This resulted in signifcant mobilsation of organigic matter and a change of water quality. In this study, we consider the time period of before and during the wind disturbance period to identify impacts on DIN (dissolved inorganic nitrogen) and DOC (dissolved organic carbon) with a process based simulation model.


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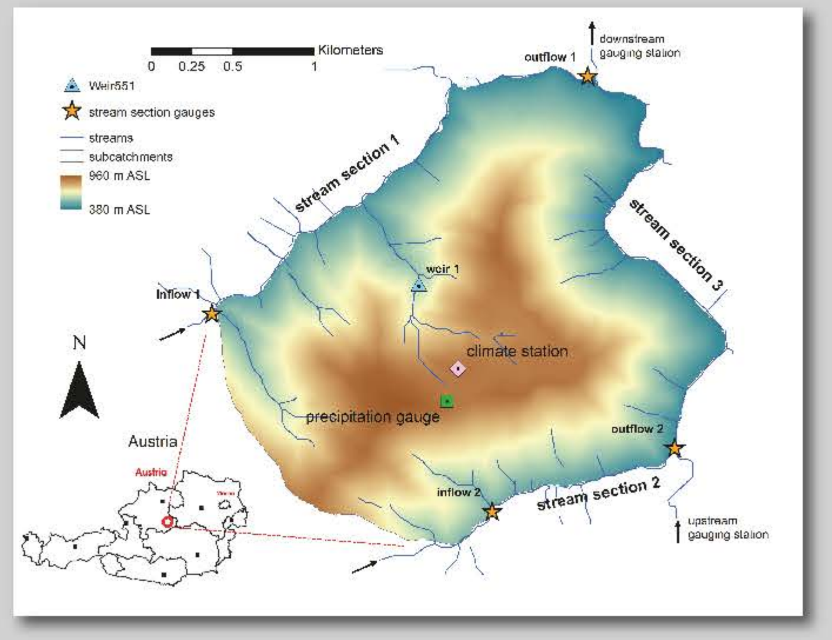
STUDY SITE



The study site LTER Zöbelboden is located in the northern part of the national park "Northern Limestone Alps". Its altitude ranges from 550 m to 956 m ASL. Due to the dominating dolomite, the catchment is not as heavily karstified as limestone karst systems, but shows typical karst features such as conduits and sink holes.
Discharge (entire karst system and weir, daily resolution) and hydrochemical observations (weir, DOC and DIN, weekly resolution) were available from 2002-2012.

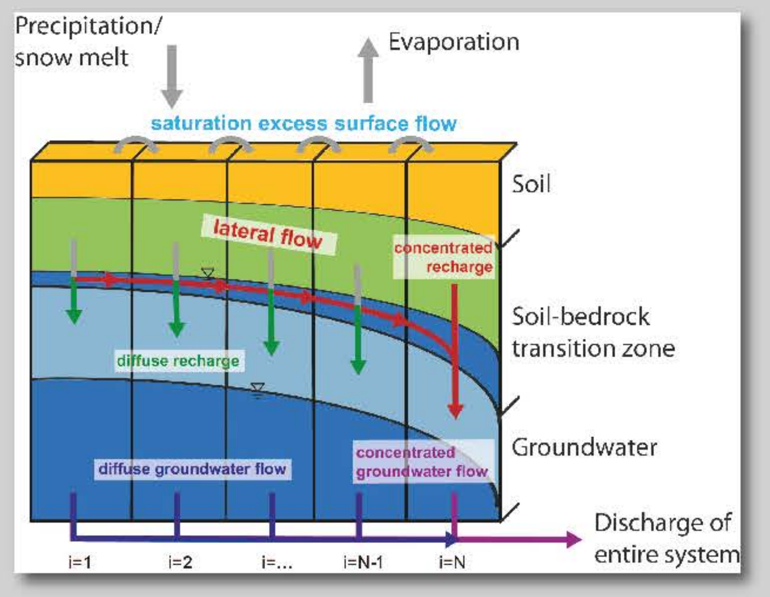
METHODOLOGY

The simulation model considers the variability of karst system properties by statistical distribution functions. That way it simulates a range of variably dynamic pathways through the karst system. To consider also the production and leaching dynamics of DOC and DIN the hydrodynamic routines of the model were equipped with non-conservative solute transport routines.

For evaluation and impact analysis we use a split-sample test and the Kling-Gupta efficiency (KGE):

$$KGE = 1 - \sqrt{(r-1)^2 + (\alpha-1)^2 + (\beta-1)^2}$$

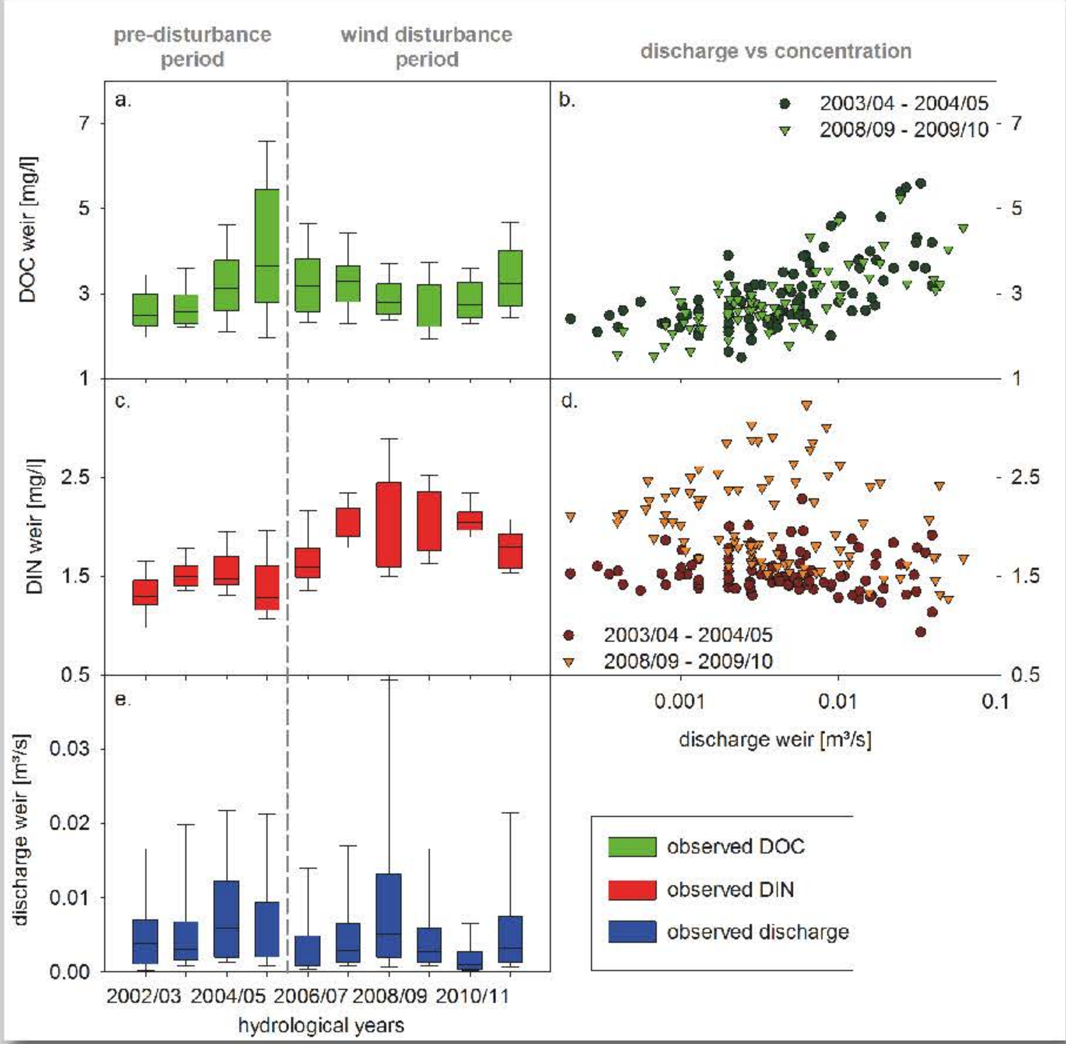
$$\alpha = \frac{\sigma_S}{\sigma_O} \text{ and } \beta = \frac{\mu_S}{\mu_O}$$



The model is calibrated and evaluated during the pre-disturbance period (02/03-05/06). This period is too short to define a calibration and a validation period. Instead, two samples are created by bootstrapping from all pre-disturbance observations and a both-sided split sample test is performed.

For the disturbance period deviations of the simulated solutes indicate changes of DOC and DIN dynamics. The three components of KGE allow identifying temporal shifts (r), changes of concentration fluctiations (α) and changes of solute production and leaching (β).

IMPACT OF DISTURBANCE



Around 5-10 % of the study site has been subject to windthrow.

There is a positive correlation between concentrations and discharge. But there is no change in intra- and inter-annual variability of DOC concentrations before and during the disturbance.

There is no obvious relation between discharge and DIN concentrations. But they show a clear increase during the disturbance period.

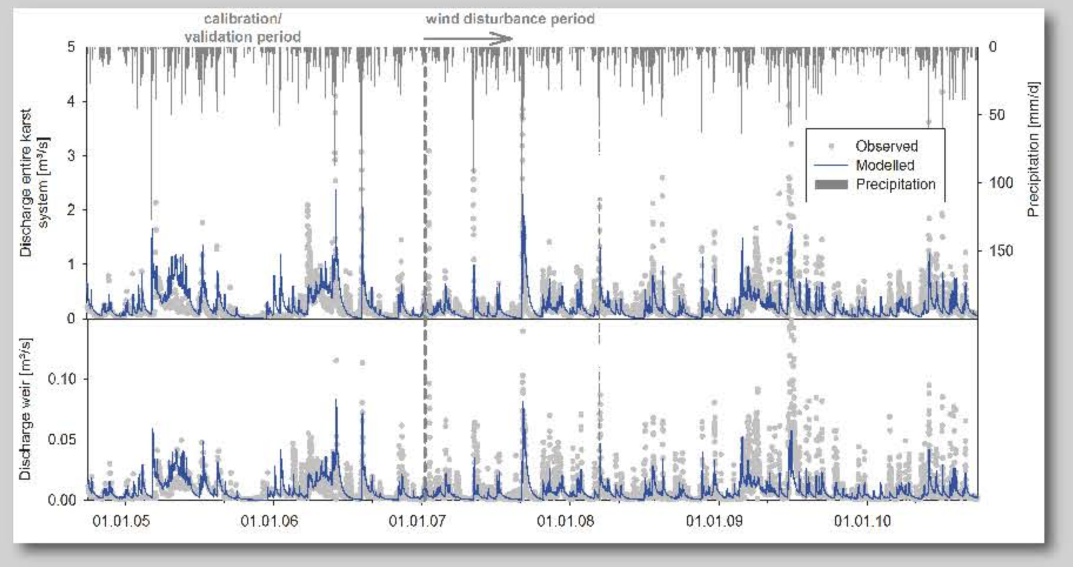
MODEL PERFORMANCE

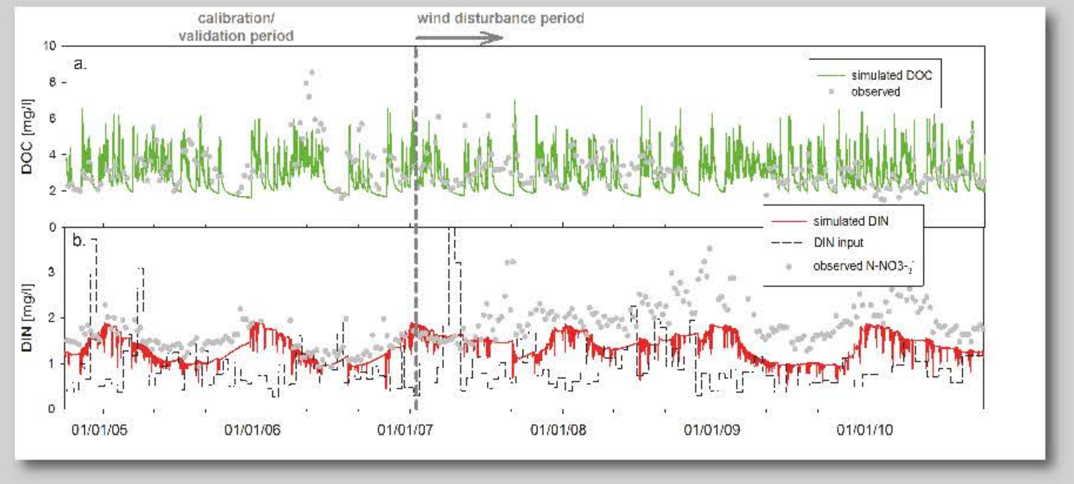
KGEs for the different simulation variables indicate an adequate model performance and an acceptable stability for their validation data sets. Calibration on both samples provided similar parameter values.

Performance	Sample 1	Sample 2
$KGE_{weighted}$	0.56/0.49*	0.52/0.53*
$KGE_{Q,tot}$	0.41/0.33*	0.35/0.42*
$KGE_{Q,W}$	0.67/0.62*	0.61/0.66*
KGE_{DOC}	0.38/0.35*	0.43/0.32*
KGE_{DIN}	0.48/0.40*	0.48/0.45*
KGE_{SO4}	0.74/0.62*	0.64/0.65*

* calibration/validation other sample

With the beginning of the disturbance, the model starts to under-estimate DIN concentrations.





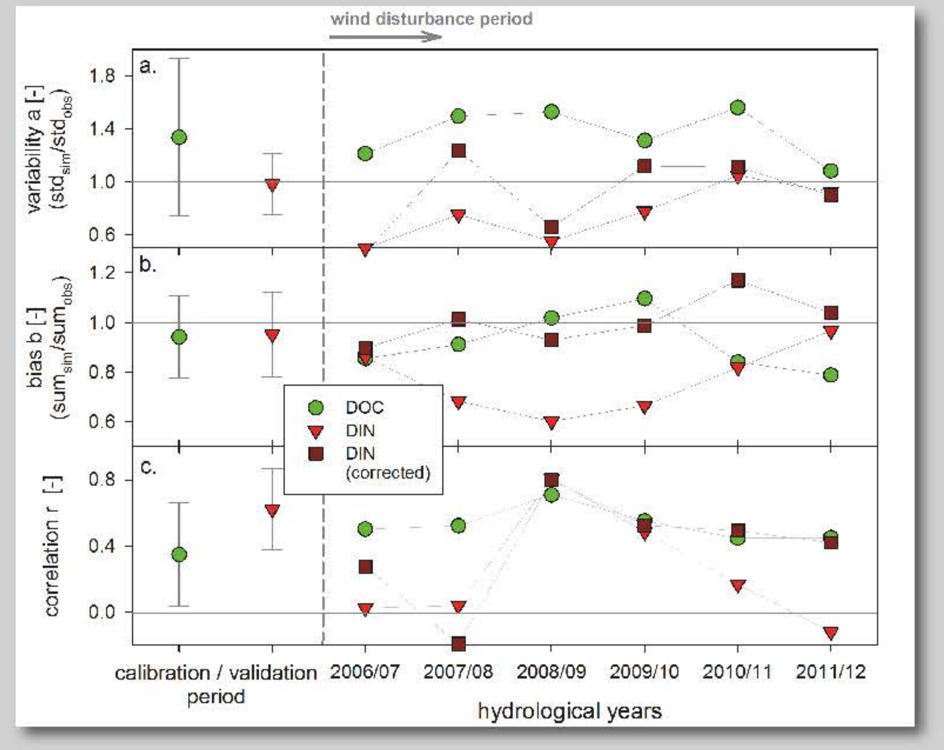
MOBILISATION OF DIN

The individual components indicate a significant deviation of simulated DIN concentrations during the disturbance period. Variability α and bias β are under-estimated, while correlation r is lower than during the calibration and validation period.

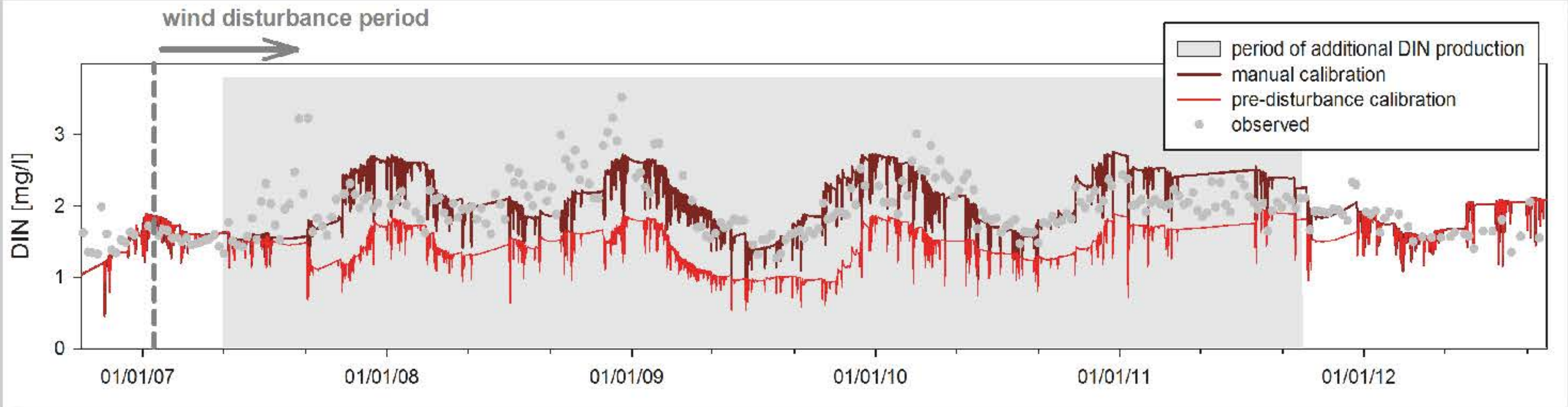
A correction of the DIN production parameters in the model during the disturbance period improved the DIN simulation performance. They indicate an overall increase of DIN production, a decrease of production variability, and a shift of production seasonality for the time period May 2007 - Sep 2011.

Performance	Calibration type	
	Pre-storm	corrected
KGE_{DIN} *	0.29	0.41
variability α_{DIN} *	0.75	1.04
bias β_{DIN} *	0.70	1.01
correlation r_{DIN} *	0.40	0.41

* for 2006/07-2011/12



The deviations between simulated and observed DIN concentrations indicate an additional release of 11.9 kg/ha of DIN over the whole period of ~3.5 years, or 2.7 kg/ha/a. Considering an average release of 5.2 kg/ha/a the impact of the storm resulted an increase >50% in of DIN.



SYNTHESIS

Our simple modeling approach enabled us to assses the impact windthrow disturbances at an Austrian karst system. Disregarding the damaging processes our simulation model could be used a a base-line for the undisturbed system allowing for quantification of DIN mobilisation. A correction of the model parameters to improve the simulations during the disturbance period additonally revealed changes in the production dynamics of DIN.

Overall, our study shows that windthrow disturbances of ≤10% can producte massive mobilisation of DIN of >50%.

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