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EFFECTS OF SITE CHARACTERISTICS ON CUMULATIVE FREQUENCY DISTRIBUTION OF WATER TABLE DEPTH IN PEATLANDS

Michel Bechtold, Bärbel Tiemeyer, Enrico Frahm, Annette Freibauer

von Thünen-Institut (vTI), Institute of Agricultural Climate Research, Bundesallee 50, D-38116 Braunschweig, Germany, +495315962657, michel.bechtold@vti.bund.de

SUMMARY

Water table depth is the key parameter controlling the fluxes of CO_2, CH_4 and N_2O from peat soils. An improved knowledge about its annual dynamics and the dependence on site characteristics can improve the regionalization of water table depth and greenhouse gas emissions. We propose that the beta continuous density function is suited for characterizing the shape of water table depth frequency distributions. Our analysis of continuous water level records in 70 peatland sites shows that land use type, peatland type, catchment size and soil properties are promising upscaling parameters.

KEYWORDS: hydrology, peatland, water table depth, regionalization, beta distribution

INTRODUCTION

Drained peat soils in agricultural use account for 4-5% of total greenhouse gas (GHG) emissions in Germany. There is an increasing effort to adjust land use and water management with the goal to reduce these emissions. Research during the last two decades demonstrated that water table depth is the key parameter controlling the fluxes of CO_2, CH_4 and N_2O from peat soils (Moore and Dalva, 1993). Recent meta analyses combining data from several annual and multi-annual time series of GHG fluxes showed strong dependency of the total annual emissions on annual mean water table depth (Drösler, *et al.*, 2011). It is also proposed that the duration of ponding and low water level periods within a year are important indicators for the height of the annual emissions of CH_4 and CO_2 (Hahn-Schofl, *et al.*, 2011). Thus, the distribution function of the water table depth contains valuable information for GHG fluxes. These functions could be considered as an equivalent to flow duration curves which are frequently used as a basis for the regionalisation of the hydrological behaviour of catchments (Holmes, *et al.*, 2002). Spatial information on the annual mean and dynamics of water table depth in German peat soils is essential for a nation-wide upscaling of local gas flux measurements and for estimating the impact of regional mitigation strategies.

In the course of the installation of GHG measurement sites in 11 peatlands that cover the variety of typical German peatland types, a monitoring network of groundwater and surface water level loggers has been installed. One objective of this network is the derivation of functional dependencies between water table dynamics and site characteristics as land use, ditch density, soil properties, catchment size, stratigraphy, climate and peatland type. Using nation-wide spatially available input data, these dependencies can be used for the regionalization of water table depth. In this paper, we present preliminary results of the evaluation of a data subset of the monitoring network, i.e. the first year of 70 continuous time series. We discuss the controlling factors that influence the annual mean and frequency distribution of water table depth.

MATERIAL AND METHODS

We analyzed groundwater level data from 70 'Diver'-dataloggers (Schlumberger Water Services) with 15 min temporal resolution. After plausibility checks, outlier detection and smoothing, daily averages were calculated. 70 full years of daily water level data were analyzed for mean and parameters describing the annual water level variation.

Numerous environmental variables do follow a beta distribution, as for example runoff coefficients in hydrology (Gottschalk and Weingartner, 1998) or humidity in meteorology (Yao, 1974). The beta distribution is very flexible to model variables, which are lower and upper bounded. Beta densities can be unimodal, uniantimodal, increasing, decreasing or constant. We applied the beta distribution to our dataset of water level frequency distributions and found that the beta continuous density function can describe most of the shapes of observed water level frequency distributions fairly well. We used the beta distribution to obtain a quantitative characterization of the observed frequency distribution of water table depth.

The probability density function (PDF) of a random variable X that is beta-distributed between X_{min} and X_{max} is,

$$f_x(X) = \frac{1}{B(a,b)} \frac{(X - X_{\min})^{a-1}(X_{\max} - X)^{b-1}}{(X_{\max} - X_{\min})^{a+b-1}}$$

where B(a,b) is the beta function with the shape parameters a and b. In this study, X is water level relative to soil surface, and X_{min} and X_{max} are the minimum and maximum water level relative to soil surface within a year. In the following, we also show the cumulative distribution function (CDF) of the beta distribution, which describes the probability that X is lower than a specific value. Values of X_{min} and X_{max} were directly obtained from the continuous daily-averaged time series. To estimate the parameters a and b of the beta distribution, we used the method of moments, in which a and b are calculated from the first and second moment (mean and variance) of the water level data. For continuous time series of daily averages of water table depth, this approach guarantees that both data and beta distribution have the same mean and variance.

RESULTS AND DISCUSSION

Water management is the primary factor controlling the mean annual water level in drained peatlands. In Germany, nation-wide information about the management of surface water levels in drained peatlands is not available. Because water management is designed to allow for a certain land use, the nation-wide available land use information must be used as primary indicator for mean annual water level in a regionalization approach. Figure 1 demonstrates the strong dependency of mean annual water level on land use type. In the box plot, we differentiated between intensively (2 or more cuts per year) and extensively (0 or 1 cut) used grassland, an information which is not available at the national scale.

To explain the high variance of water table depth within most land use categories, secondary factors that are nation-wide available must be found. Estimates of the annual precipitation surplus, peatland type and soil properties derived from soil maps may be promising to differentiate between the land use types or to define new water level categories. For example, our dataset indicates a high correlation (R^2=0.61) between the bulk density (average 0-1 m) and mean annual water table depth (Fig. 2). This correlation is strongly related to the long term peat degradation caused by a specific water management, but probably also reflects the dependency of hydrologic response and hydraulic properties on bulk density. In future work, we will apply multivariate statistical methods to systematically cluster peatland sites into groups of similar mean and annual dynamics of water table depth.

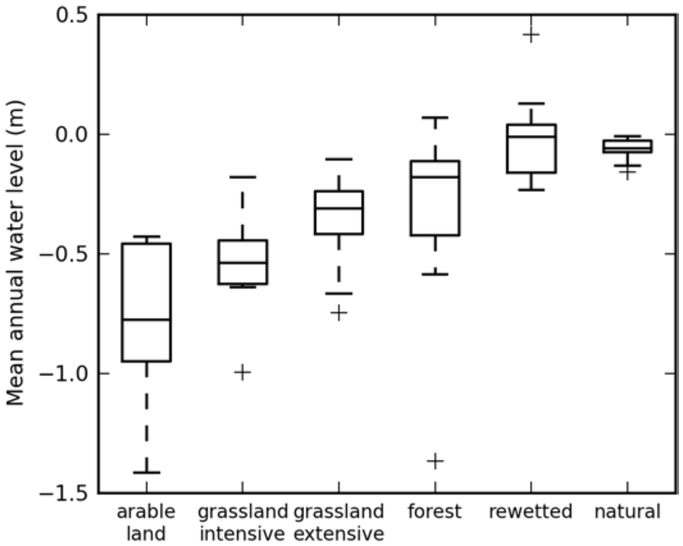

Fig. 1: Mean annual water level relative to soil surface (m) as a function of land use.

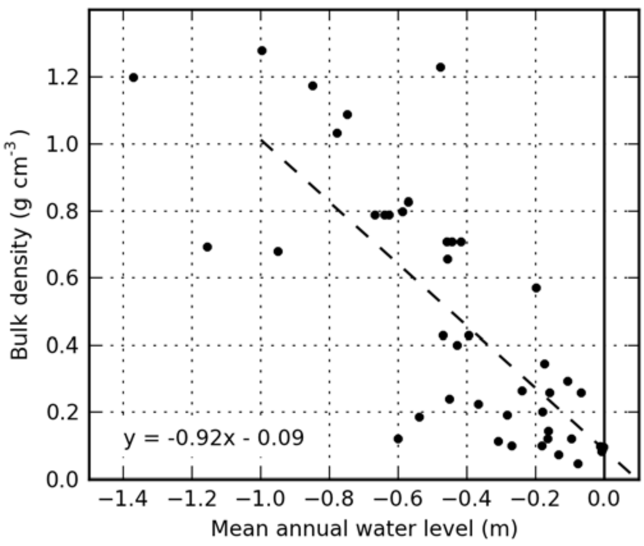

Fig. 2: Bulk density (g cm^{-3}) as a function of mean annual water level relative to soil surface (m).

In the following, the controlling factors that influence the shape of water level frequency distributions are discussed. The observed cumulative distribution functions (CDFs) can be divided in four major categories (Fig. 3). The first three categories can be differentiated by their skewness which change from positive (left-skewed) to negative (right-skewed) from (a) to (c). The intermediate category (b) represents a uniform-like distribution, which would result from a sinus-shaped water level time series. A forth group of 'S'-shaped CDFs is obtained by defining thresholds on parameters describing the shape of the distribution (skewness<0.5, variance normalized by the square of the amplitude <0.055, sum of a and b > 4).

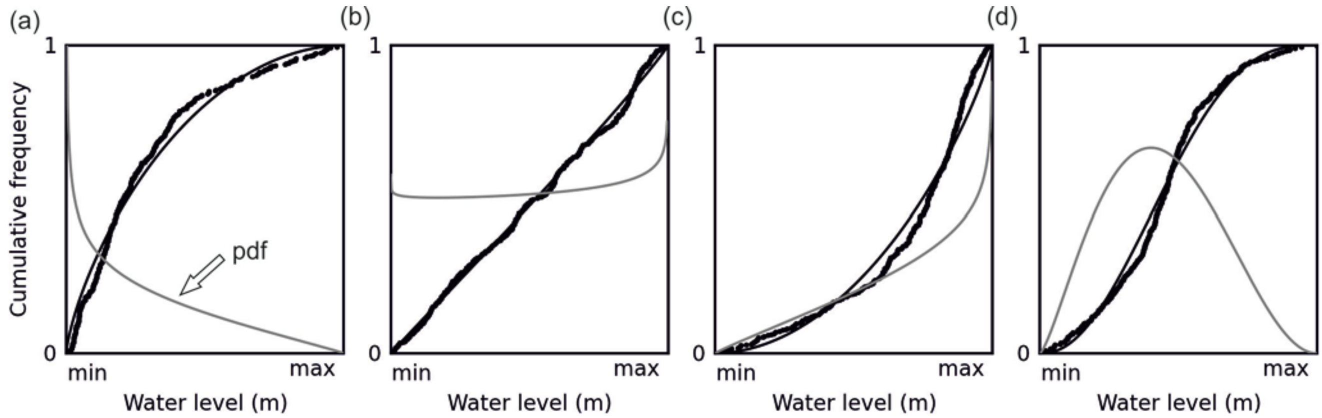

Fig. 3: Cumulative frequency (black line: beta distribution, black dots: observed data) and probability density function (grey line) as a function of water level. Shown are examples of four different peatland sites representing the four categories.

Figure 4 shows high correlation of skewness with annual mean water table depth both for fens with and without an underlying peat clay layer. Data from bogs and other organic soils not classified as peatlands (soil organic matter 15-30%) did not cover the range of mean annual water levels with sufficient data. The trend of more negative skewness with increasing water level can be explained by the increasing storage capacity during high water levels when water is stored in surface depressions or over the whole surface. This dampens further water level rise and leads to higher frequency of levels close to the maximum. In fens without a confining peat clay layer the dampening is less pronounced because ground and surface water inflow from the catchment sustain a further water level rise during wet periods (Fig. 4). Consequently, with an increasing catchment size to peatland area ratio, skewness should be even more shifted to more positive values. Figure 4b is based on data of three different peatlands which support this shift. A negative skewness can be also interpreted as an indicator for the naturalness of the peatland as it can be explained by a high storage capacity at high water levels due to high percentage of large pores and swelling property of peat.

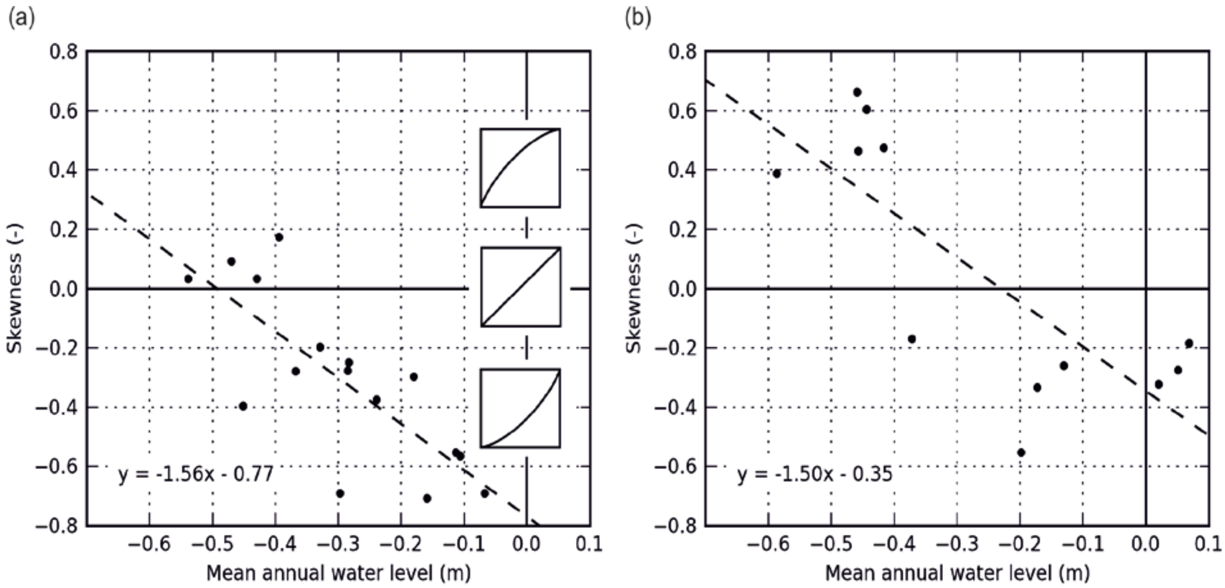

Fig. 4: Skewness as a function of mean annual water level relative to soil surface for fens with (a) and without (b) and underlying peat clay layer.

Besides peatland type and catchment size, land use type was found to be a third factor influencing the shape of the CDFs. The group of 'S'-shaped CDFs comprises 13 of 15 forest sites on all peat types. The two remaining forest sites, with distributions that are not 'S'-shaped, are characterized by a low C_{org} content and dry conditions. The group of 'S'-shaped CDFs also comprises 7 sites with a different land use and vegetation cover, which however are located adjacent to forests or present a sparse tree cover. Thus, 'S'-shaped CDFs seem to reflect the influence of forests on local water table dynamics. We refer this effect to the high evapotranspiration from forests even during periods of low water table depth, which causes the pronounced tail in the CDFs close at the minimum end of the frequency distribution.

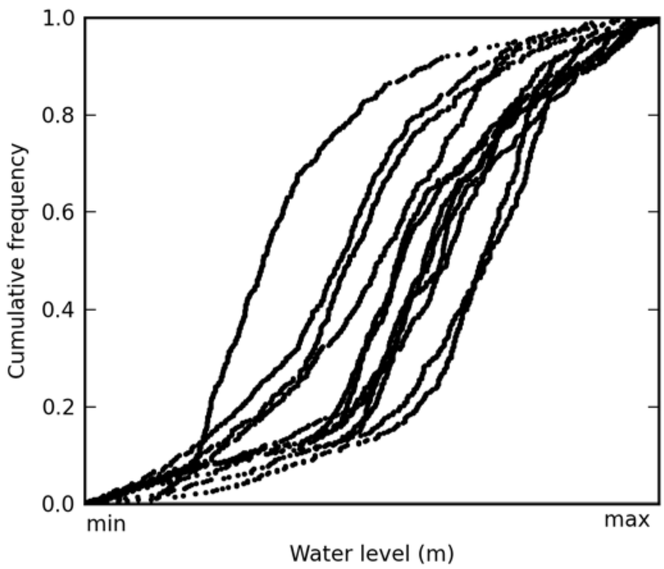

Fig. 5: Cumulative frequency distribution of observed water levels shown for 13 forest sites.

CONCLUSIONS AND OUTLOOK

Frequency distributions of continuous water level records in 70 peatland sites were well approximated with the beta continuous density function. The beta distribution is thus a promising tool to consistently classify the shape of water table depth frequency distributions. The dataset presented a large variation of shapes of water table probability density functions. Some of this shape variety could be explained by the mean annual water table depth. However, the same mean annual water table depth can still be associated to very different frequency distributions. As the emissions of CO_2, CH_4 and N_2O are the product of the superposition of various factors, emissions do not linearly increase with decreasing water levels. Therefore knowledge about both the mean and shape of frequency distributions of water table depth is important. Regarding the regionalization of mean and dynamics of water table depth, our results indicate that land use type, peatland type, catchment size and soil properties are promising upscaling parameters. In future work, an extended dataset including data from a newly created nation-wide database of peatland restoration activities will be evaluated with multivariate statistical methods to systematically combine peatland sites into groups of similar mean and annual dynamics of water table depth.

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REFERENCES

Drösler, M., *et al.* (2011). Klimaschutz durch Moorschutz in der Praxis, Ergebnisse aus dem BMBF-Verbundprojekt „Klimaschutz - Moornutzungsstrategien“ 2006-2010, *vTI-Arbeitsberichte 4/2011*.

Gottschalk, L. and Weingartner, R. (1998). Distribution of peak flow derived from a distribution of rainfall volume and runoff coefficient, and a unit hydrograph, *Journal of Hydrology*, *208*(3-4), 148-162.

Hahn-Schofl, M., *et al.* (2011). Organic sediment formed during inundation of a degraded fen grassland emits large fluxes of CH4 and CO2, *Biogeosciences*, *8*(6), 1539-1550.

Holmes, M.G.R., Young, A.R., Gustard, A. and Grew, R. (2002). A region of influence approach to predicting flow duration curves within ungauged catchments, *Hydrology and Earth System Sciences*, *6*(4), 721-731.

Moore, T.R. and Dalva, M. (1993). The Influence of Temperature and Water-Table Position on Carbon-Dioxide and Methane Emissions from Laboratory Columns of Peatland Soils, *Journal of Soil Science*, *44*(4), 651-664.

Yao, A.Y.M. (1974). Statistical-Model for Surface Relative Humidity, *Journal of Applied Meteorology*, *13*(1), 17-21.