Storm-related characteristics of the turbulent airflow above a Scots pine forest

Dirk Schindler and Helmut Mayer

Meteorological Institute, University of Freiburg, Germany

1. Introduction

During the last few decades, Germany and its neighbouring states were hit by several storms which caused extensive damages in managed forests (LFV, 1994; KRONAUER, 2000; WSL and BUWAL, 2001). Besides the economic consequences (e.g., KRONAUER, 2000; CLARKE, 2001), wind damages disturb silvicultural and forest protection operational procedures (ROTTMAN, 1986; ULANOVA, 2000). Based on statistical analysis of long-term wind speed data (e.g., SCHROERS and LÖSSLEIN, 1983) and modelling of the future development of near-ground wind speeds (KNIPPERTZ et al., 2000), which indicate a shift towards higher mean wind speeds as well as towards higher peak wind speeds under certain weather situations over large parts of Europe, a further increase of the risk of wind damages in forests is to fear.

2. Wind damages in forests

Wind damages in forests can initially be caused by both extreme mean wind speeds and dynamic turbulence, i.e. wind damages in forests are triggered by airflow characteristics. In a first step, they lead to damped tree swaying of irregular pattern (MAYER, 1985; PELTOLA, 1996) depending on various site and stand factors (Fig. 1).

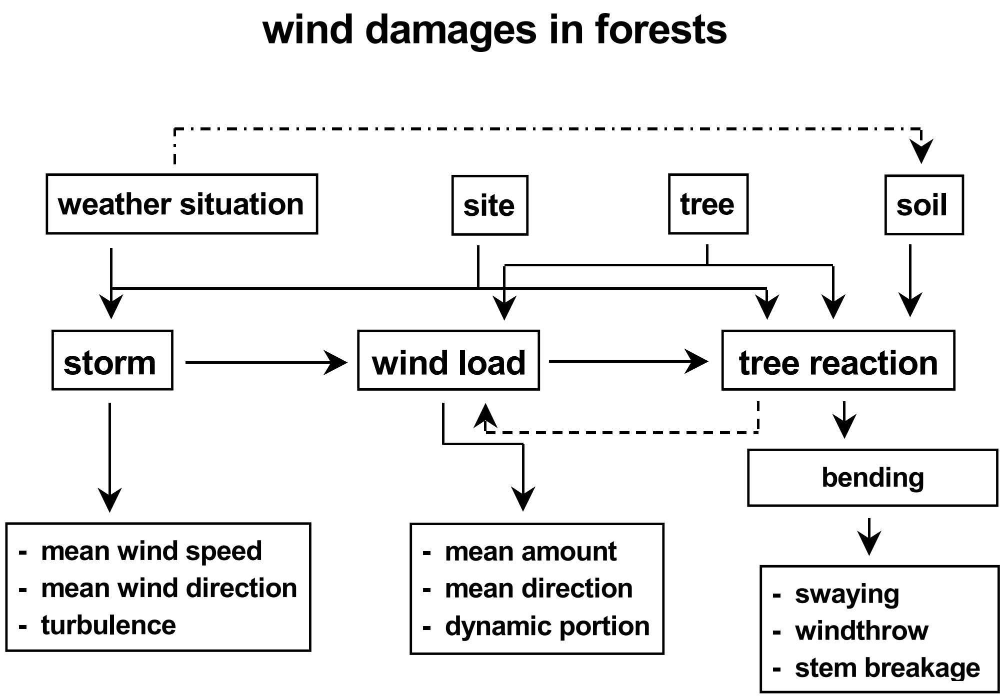

Fig. 1: Interactions between site and stand factors resulting in possible wind damages in forests (after MAYER and SCHINDLER, 2002)

Windthrow or stem breakage are the final tree reactions on unreasonable high wind loads. To estimate wind loads on trees, Eq. (1) can be used (GRACE, 1977):

$$K(v,z) = \frac{1}{2} \cdot \rho_L \cdot v(z)^2 \cdot C_D(v,z) \cdot A(v,z) \tag{1}$$

where K: wind-induced force at the height z as a function of wind speed v, ρ_L: air density, C_D: drag coefficient, and A: projected crown area perpendicular to the wind. Unfortunately, C_D and A vary instantaneously with changing wind speed. Therefore, they cannot be determined in a reasonable high temporal resolution during a storm event. Although approaches exist to model C_D and A (GARDINER and QUINE, 2000; GARDINER et al., 2000; PELTOLA et al., 1999a, 1999b), turbulent airflow characteristics still cause problems for the determination of reliable values of critical wind loads on trees in the necessary temporal resolution.

The aim of this study is to analyse turbulent airflow characteristics at a forest site which are relevant to understand the wind dynamics above a forest with regard to wind damages. Wind loads on trees are approximated by the shear stress τ acting on the forest canopy (MAYER, 1985, 1987).

3. Methods and data processing

3.1 Site description

Airflow characteristics were studied at the forest meteorological experimental site Hartheim (47°56´04´´N, 7°36´02´´E, 201 m a.s.l) in the southern upper Rhine plain near Freiburg, Germany. The experimental site is located in a slow-growing, even-aged Scots pine (*Pinus sylvestris* L.) patch centered within the Hartheim forest. The Scots pine patch was planted in NNE-SSW orientated rows in the year 1963 and extends 0.5 km in E-W direction and 1 km in N-S direction. The total Hartheim forest extends approximately 1.5 km in E-W direction and 4.5 km in N-S direction. In the year 2002, the mean stand height h at the experimental site was 14.2 m, the mean breast height diameter BHD was 0.16 m, the mean projected plant area index PAI was 2.9 m^2 m^{-2}, and the mean stand density 1000 trees ha^{-1}. Due to airflow channeling in the Rhine valley, prevailing wind directions are SSW and N. For a complete site description see MAYER et al. (2000).

3.2 Instruments and measurement techniques

The experimental site Hartheim is equipped with two meteorological walk-up towers (z = 21 m, z/h = 1.4; z = 30 m, z/h = 2.1) which are separated by a horizontal distance of about 40 m. The 30 m high tower carries instruments which measure continuously wind direction, short- and long-wave radiation fluxes, net all-wave radiation, precipitation, profiles of dry and wet bulb temperature and wind speed (MAYER et al., 2000). Additionally, for the period 10-01-2002 to 01-31-2003 two sonic anemometers were mounted on this tower at the height 27.9 m (USA-1; Metek, Germany) and 4.9 m (R2; Gill Instruments, UK). The USA-1 was operated at a sampling rate of 10 Hz and the R2 was operated at a sampling rate of 20.8 Hz, respectively. During the same period, a monostatic FAS64 flat array sodar (Scintec, Germany) was installed on top of the 21 m high tower to investigate structures and processes in the planetary boundary layer (PBL) above the tower height. The operating range of the FAS64 were the lowest 500 m of the PBL (layers of 20 m).

3.3 Data processing and calculations

Data of the conventional tower measurements were available as 1 h mean values, sonic anemometer data were stored as 1 h files, and the integration time of the FAS64 was 30 min. The first step of the data processing was to remove erroneous records. Missing data points and small data gaps were filled using linear interpolation. Mean statistics of the sonic anemometer data were calculated from 10 min data blocks. The fluctuation components for eddy covariance calculations were obtained applying Reynolds decomposition. Using 1h data, fast Fourier transforms (FFT) were performed to calculate power spectra of the wind vector components u, v, w, the fluctuations of the wind vector components u´, v´, w´, and of the shear stress τ. Before applying the FFT, data were despiked, linearly detrended, and the x-axis was rotated to adjust the longitudinal wind component to the streamwise direction. All spectra were smoothed by logarithmically averaging over frequency bands and the average value of a frequency band was assigned to the corresponding center frequency of the band. The FAS64 software FASrun applied intrinsic data control and data correction procedures online to the sodar data (SCINTEC, 2002).

To quantify turbulent wind loads on the Scots pine stand at the experimental site, τ was calculated by:

$$\tau = \rho_L \cdot \left|\overline{u'w'}\right| \qquad (2)$$

where ρ_L: air density, u´ and w´: turbulent fluctuations of the longitudinal and vertical wind vector components.

4. Preliminary results

To approximate wind loads on trees at the Hartheim site, τ-spectra were calculated and compared for different horizontal mean wind speeds (1 h mean values). The highest horizontal mean wind speeds above the Hartheim forest during the measurement campaign were observed on 01-02-2003. The horizontal mean wind speed measured by the USA-1 (z/h = 2.0) was 10.3 m s^{-1}. Fig. 2 shows the τ-spectrum determined at 17:00 CET on 01-02-2003 with a peak frequency of 0.04 Hz.

5. Discussion

Wind loads on trees in a forest were approximated by shear stress τ. Higher mean wind speeds above a forest lead to both higher peak frequencies in τ-spectra and to higher values of the corresponding energy. With regard to the prognosis of the future development of near-ground wind speeds over large parts of Europe, a shift of τ-spectra peak frequencies towards higher frequencies and, therefore, towards the eigenfrequency of the fundamental oscillation of trees is to be expected. Nonetheless, the probability of wind damages in forests during storms resulting from high wind loads can be reduced by silvicultural practices that minimize the effective wind loads on trees and maximize the eigenfrequency of the fundamental oscillation of trees (HOLBO et al., 1980; MAYER, 1985).

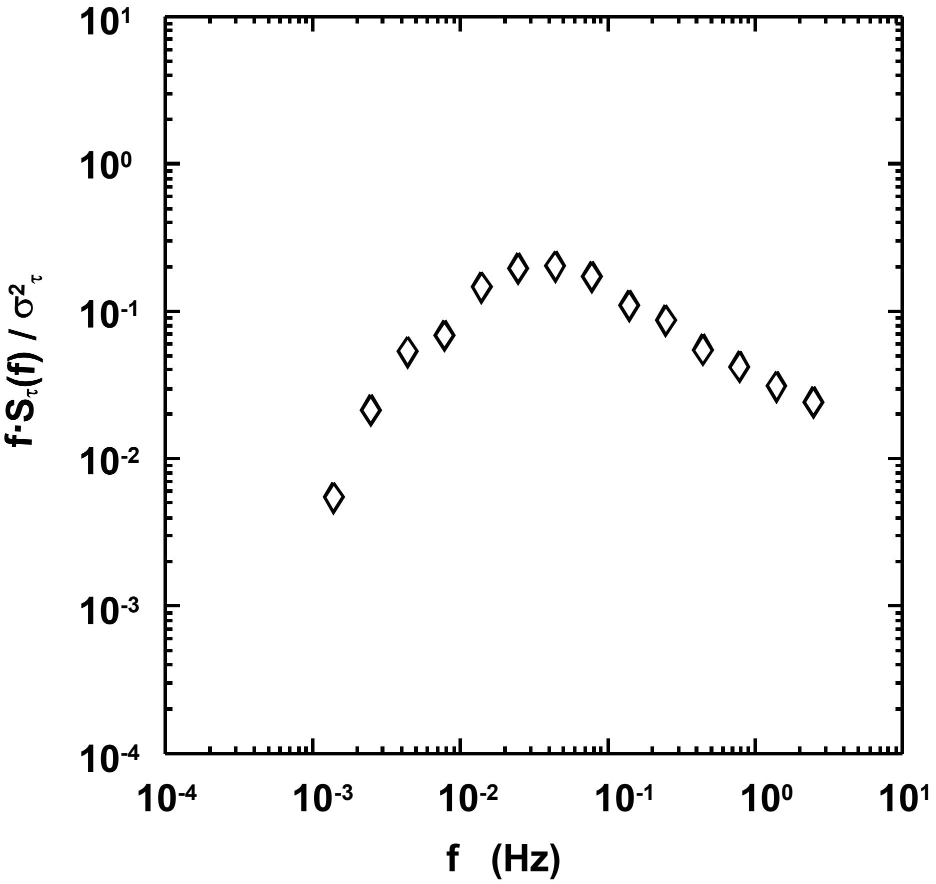

Fig. 2: Normalized τ-spectrum at the forest meteorological experimental site Hartheim at 17:00 CET on 01-02-2003 (z/h = 2.0)

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References

CLARKE, R., 2001: Lothar and Martin. WMO Bulletin **50**, 54-58.

GARDINER, B.A., QUINE, C.P., 2000: Management of forests to reduce the risk of abiotic damage – a review with particular reference to the effects of strong winds. For. Ecol. Manage. **135**, 262-277.

GARDINER, B.A., PELTOLA, H., KELLOMÄKI, S., 2000: Comparison of two models for predicting the critical wind speeds required to damage coniferous forests. Ecol. Modelling **129**, 1-23.

GRACE, J., 1977: Plant response to wind. New York, Academic Press, 204 pp.

HOLBO, H.R., CORBETT, T.C., HORTON, P.J., 1980: Aeromechanical behavior of selected Douglas fir. Agric. Meteorol. **21**, 81-91.

KNIPPERTZ, P., ULBRICH, U., SPETH, P., 2000: Changing cyclones and surface wind speeds over the North Atlantic and Europe in a transient GHG experiment. Clim. Res. **15**, 109-122.

KRONAUER, H., 2000: Lothar stellt Wiebke in den Schatten. AFZ **55**, 92-93 (*in German*).

LFV, 1994: Dokumentation der Sturmschäden 1990. Schrift. Landesforstverw. Baden-Württemberg No. 75, 1-174 pp. (*in German*).

MAYER, H., 1985: Baumschwingungen und Sturmgefährdung des Waldes. Wiss. Mitt. Meteor. Inst. Univ. München No. 51, 247 pp. (*in German*).

MAYER, H., 1987: Wind-induced tree sways. Trees **1**, 195-206.

MAYER, H., SCHINDLER, D., 2002: Forest meteorological fundamentals of storm damages in forests in connection with the extreme storm "Lothar". Allg. Forst- u. J.Ztg., **173**, 200-208 (*in German*).

MAYER, H., JAEGER, L., MATZARAKIS, A., FERNBACH, G., REDEPENNING, D., 2000: Forest meteorological experimental site Hartheim of the Meteorological Institute, University of Freiburg. Ber. Meteor. Inst. Univ. Freiburg No. 5, 55-83 (*in German*).

PELTOLA, H., 1996: Swaying of trees in response to wind and thinning in a stand of Scots pine. Boundary-Layer Meteorol. **77**, 285-304.

PELTOLA, H., KELLOMÄKI, S., VÄISÄNEN, H., IKONEN, V.-P., 1999a: A mechanistic model for assessing the risk of wind and snow damage to single trees and stands of Scots pine, Norway Spruce, and birch. Can. J. For. Res. **29**, 647-661.

PELTOLA, H., KELLOMÄKI, S., VÄISÄNEN, H., 1999b: Model computations of the impact of climate change on the windthrow risk of trees. Climatic Change **41**, 17-36.

ROTTMAN, M., 1986: Wind- und Sturmschäden im Wald. Frankfurt, Sauerländer's Verlag, 128 pp. (*in German*).

SCHROERS, H., LÖSSLEIN, H., 1983: Extremwertextrapolation und Windprofile bei Starkwind und Sturm. Meteorol. Rdsch. **36**, 205-213 (*in German*).

SCINTEC, 2002: Scintec Flat Array Sodars. User Manual. Revision 0.62b, 96 pp.

ULANOVA, N.G., 2000: The effects of windthrow on forests at different spatial scales: a review. For. Ecol. Manage. **135**, 155-167.

WSL, BUWAL, 2001: Lothar. Der Orkan 1999. Ereignisanalyse. Eds. Eidg. Forschungsanstalt WSL, Bundesamt für Umwelt, Wald und Landschaft BUWAL, 400 pp. (*in German*).