Statistical modeling of turbulent wind velocity at canopy top: application to forest wind damage

Sylvain Dupont

STATISTICAL MODELING OF TURBULENT WIND VELOCITY AT CANOPY TOP: APPLICATION TO FOREST WIND DAMAGE

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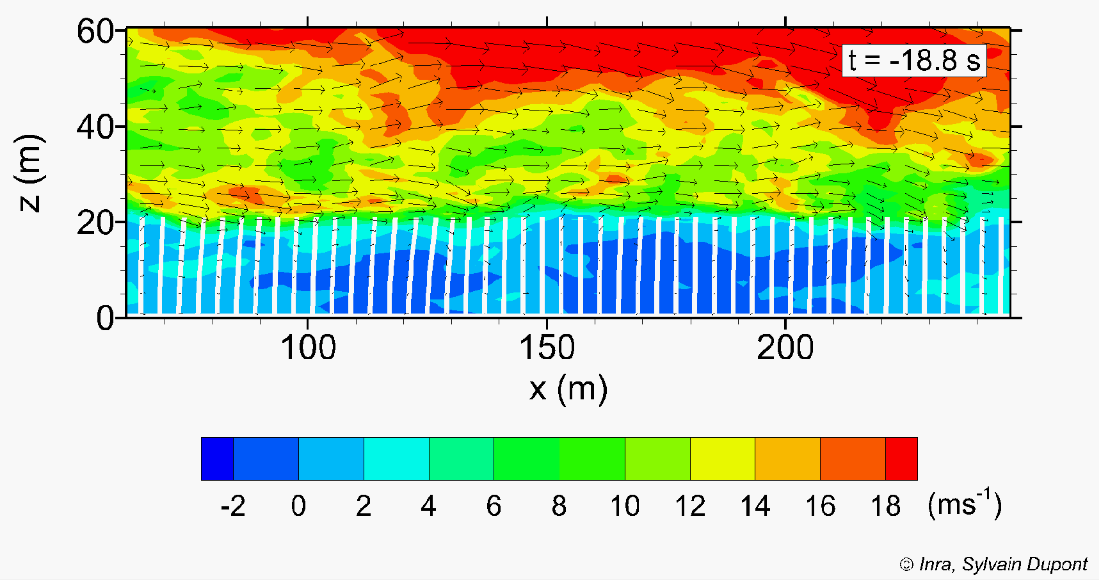
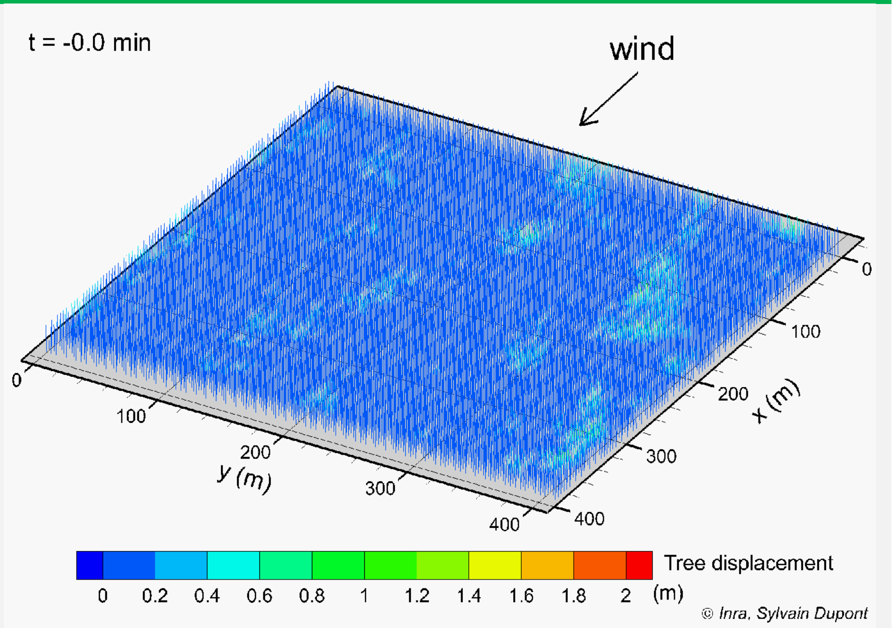
Recent findings

Dupont et al., Agric. For. Meteorol. (2015)





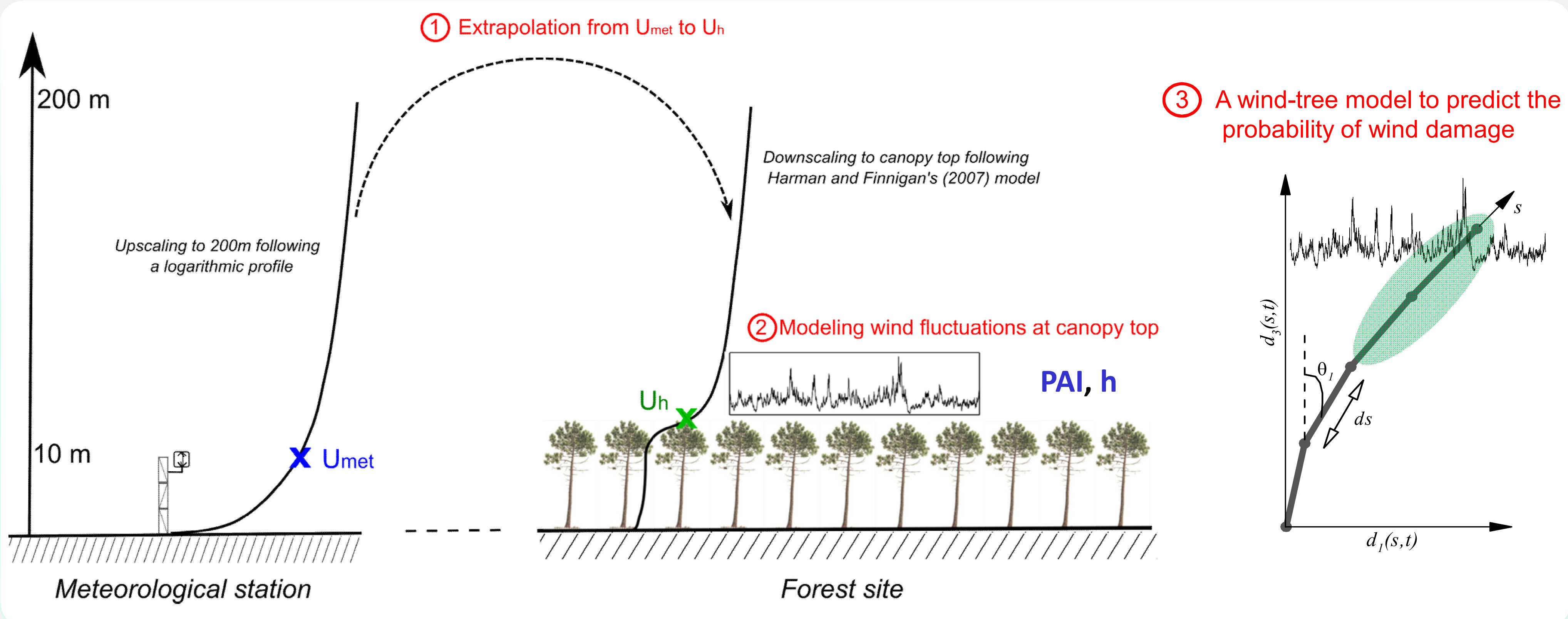
- damage propagation involves two stages
- 1st stage: randomness nature of damages, damages induced by sweeps
- 2nd stage: wind increases inside damaged areas
- storm duration plays a major role for predicting the final level of damage
- tree dynamics has to be considered in evaluating the critical bending moment

► Give clues to develop a new generation of mechanistic wind risk model

A new generation of wind risk model

- use a probabilistic approach
- account for the gustiness of the flow
- account for damage propagation
- account for windstorm duration and its intensity variation (ideally measured at a nearby meteorological station)
- allow to easily compare damage prediction between different stands or different storms as well as to investigate the impact of silvicultural practices

Proposition



- ► Tree: flexible cantilever beams, perfectly clamped in the ground (Pivato et al. 2014)
- ► Wind: statistical modeling of wind velocity time series at canopy top

Wind time series from U_h, h and PAI

- **1st step: autocorrelated Gaussian time series m_i:**

1st way: stochastic approach

- Integral scale of turbulence (**Λ_i**)
- No correlation between u and w at this stage

2nd way: inv. Fourier transform

- Energy spectra of m_i (**S_i**)
- Correlation between u and w done through phase dependence (**S_{uw}**)

- **2nd step: transformation from Gaussian to real PDF**

m_i => normalized u_i^* ($=[u_i - U_h\delta_{i1}]/\sigma_i$)

F_i: CDF of u_i^*

(1st way: correlation between velocity components done through F_i)

- **3rd step: denormalization**

$\sigma_i = e_i U_h$

$$u_i(t) = \sigma_i(u_i^*(t) + U_h\delta_{i1})$$

Main hypothesis

Unknown variables of the model:

β_N: "extinction coefficient" of the mean wind velocity within the canopy

Λ_i: integral scale of turbulence for the wind velocity u_i (1st way)

S_i, S_{uw}: analytical wind spectra and cospectrum (2nd way)

e_i: ratio between u_i standard deviations and U_h

F_i: CDF of the wind velocity u_i*

Hypothesis: *Above variables are independent of the wind intensity and canopy morphology*

Supporting reasons:

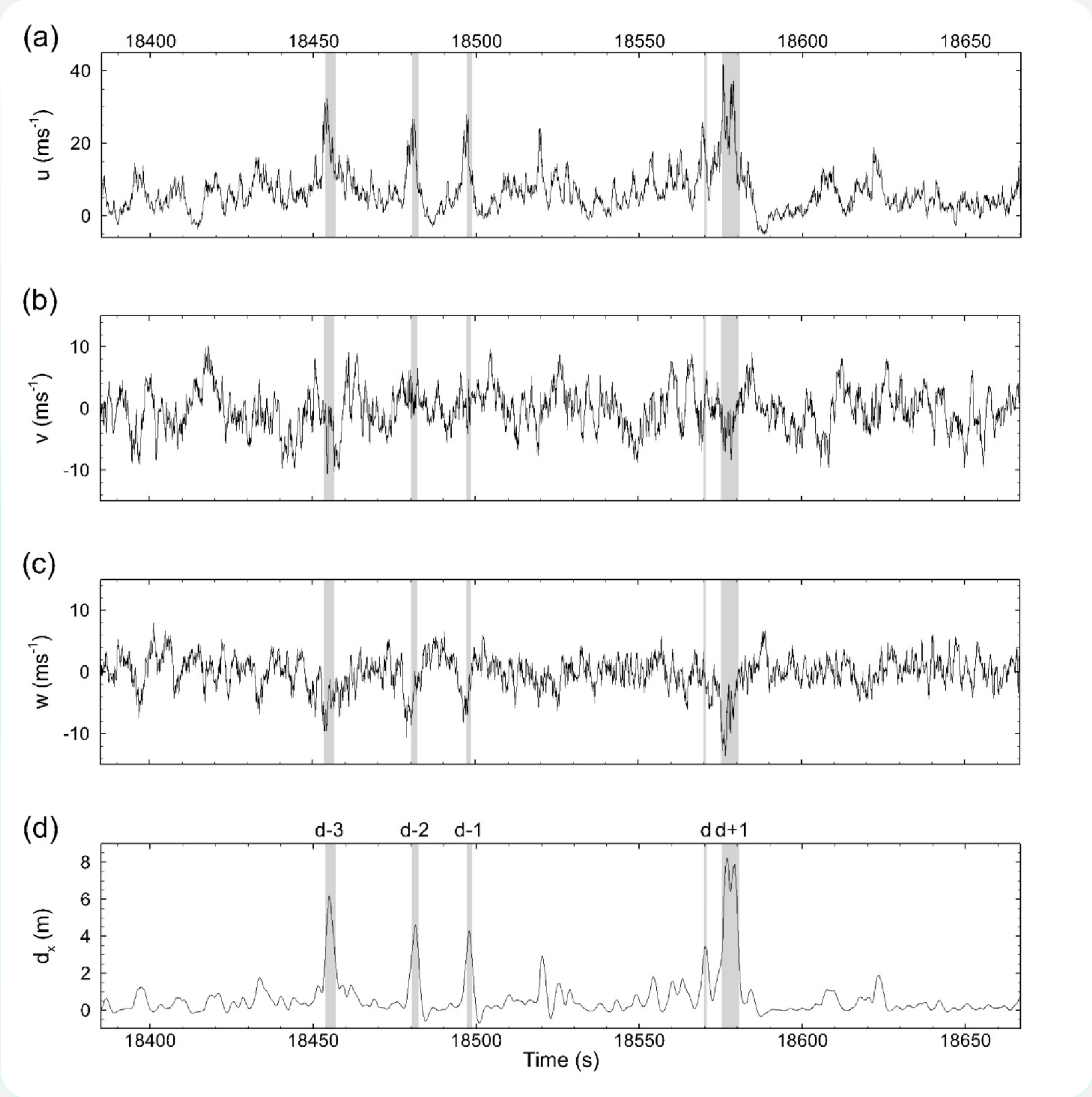
- β_N usually around 0.30 (Harman & Finnigan 2007)
- Constancy of Λ_i over a large range of canopies (Kaimal & Finnigan 1994)
- Observations and simulations showed small variabilities of normalized wind statistics at canopy top (e.g., Raupach et al. 1996, Dupont & Brunet 2008)

Limits:

- Hypothesis only valid at canopy top (inflection point position)
- Hypothesis not valid over very sparse canopies

► Following this hypothesis, β_N, Λ_i, e_i and F_i deduced from LES over a Maritime pine forest

Illustration of simulated time series of wind speed and tree motion



<u>Velocity of damage propagation:</u>

Deduced from the number of damaging periods

<u>Hypothesis:</u>

Impact of damaged areas on the wind neglected

<u>Limits:</u>

- Only valid for short or weak windstorm

But allows comparison of stand vulnerability following stand morphology

Wind model evaluation: method

Two different canopy species:

- 3 Mature Maritime pine forests, h = 22 m and PAI=1.25, 2.50, 5.00
- Walnut orchard, h = 10 m and PAI=2.50

Evaluation against measurements:

- Maritime pine forest (PAI=2.50): Le Bray experiment (Dupont et al. 2011, 2012)
- Walnut orchard: CHATS experiment (Patton et al. 2011)

Evaluation against LES:

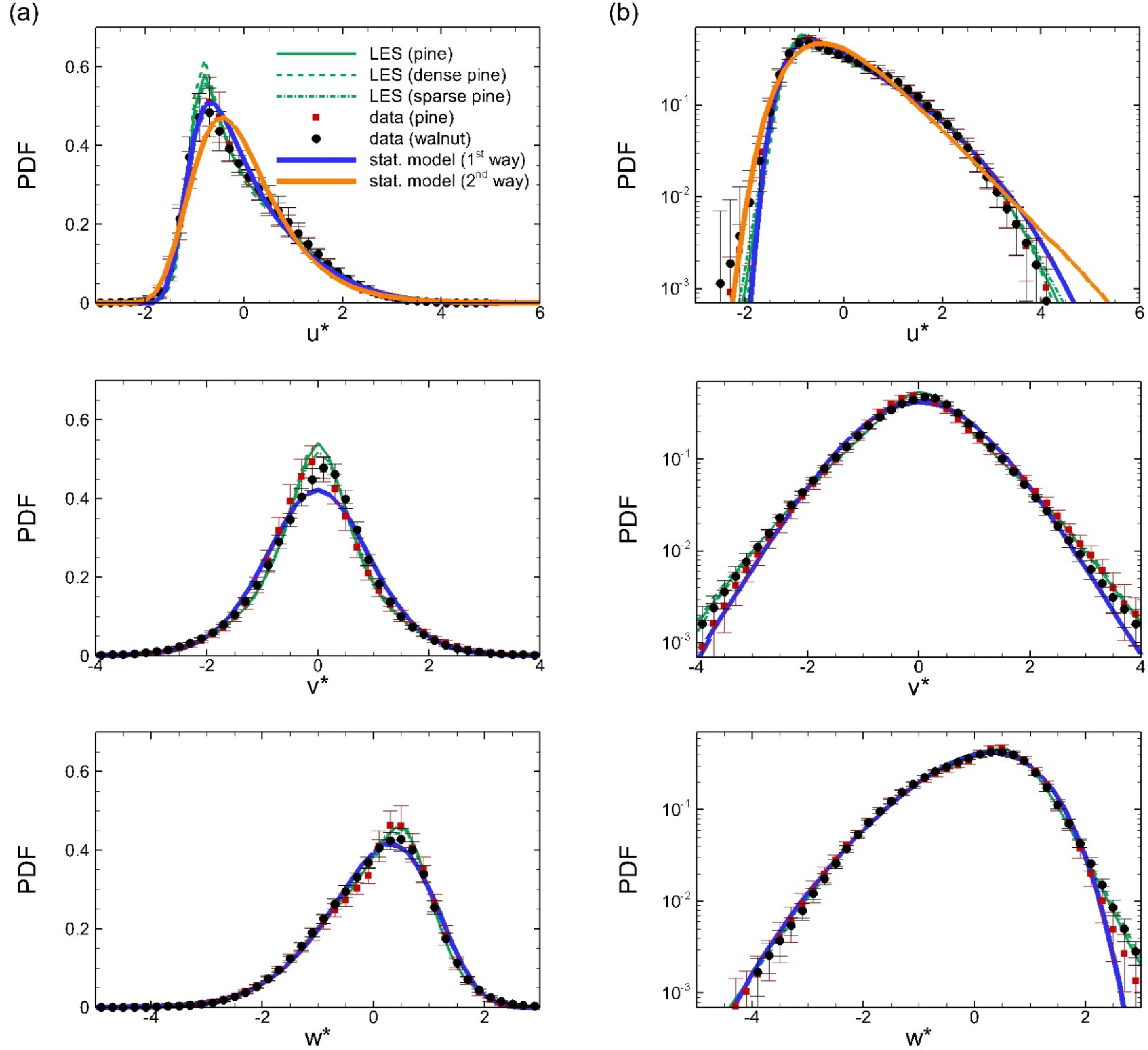
- Maritime pine forest (PAI=1.25, 2.50, 5.00)

Wind model evaluation: probability density functions

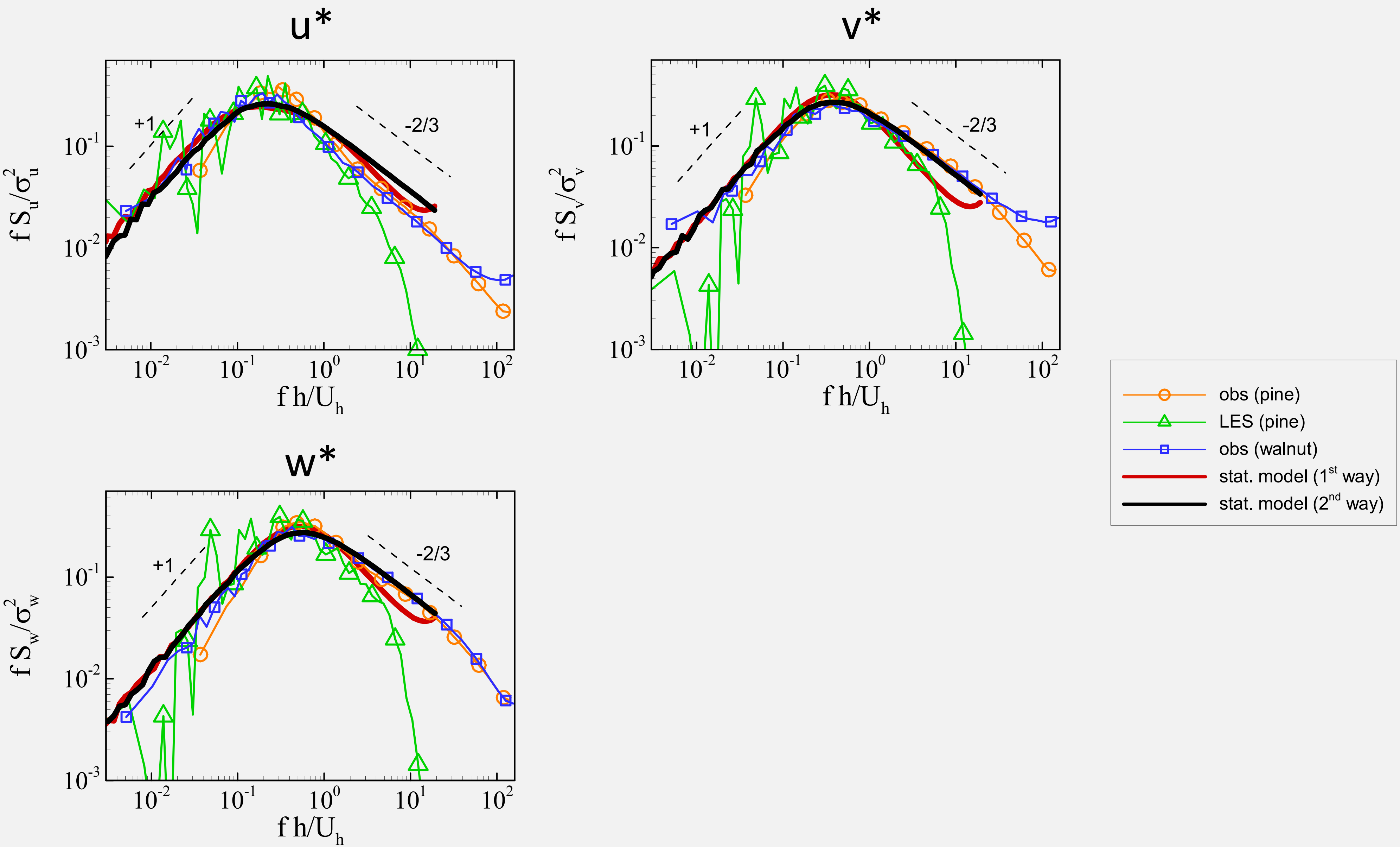
u*

v*

w*



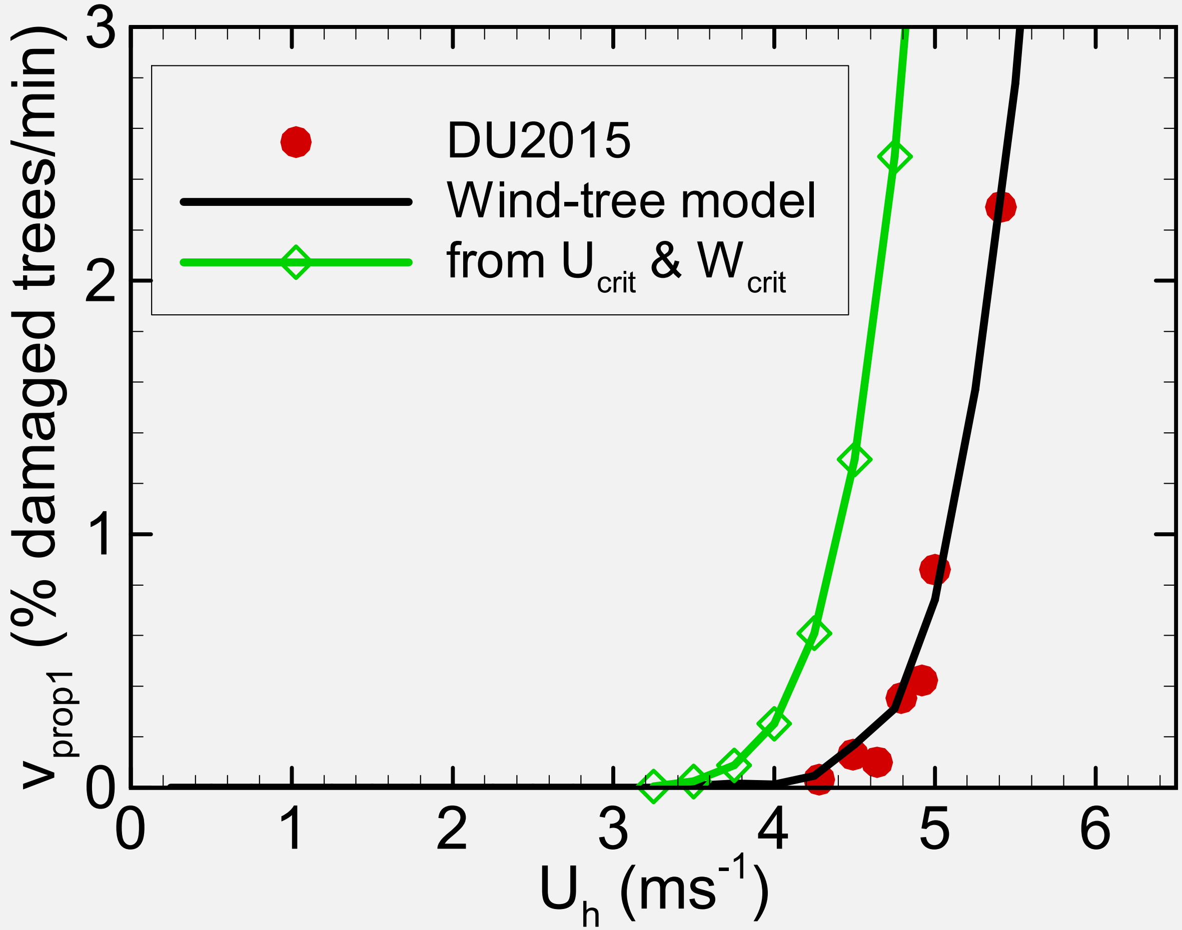
Wind model evaluation: wind spectra



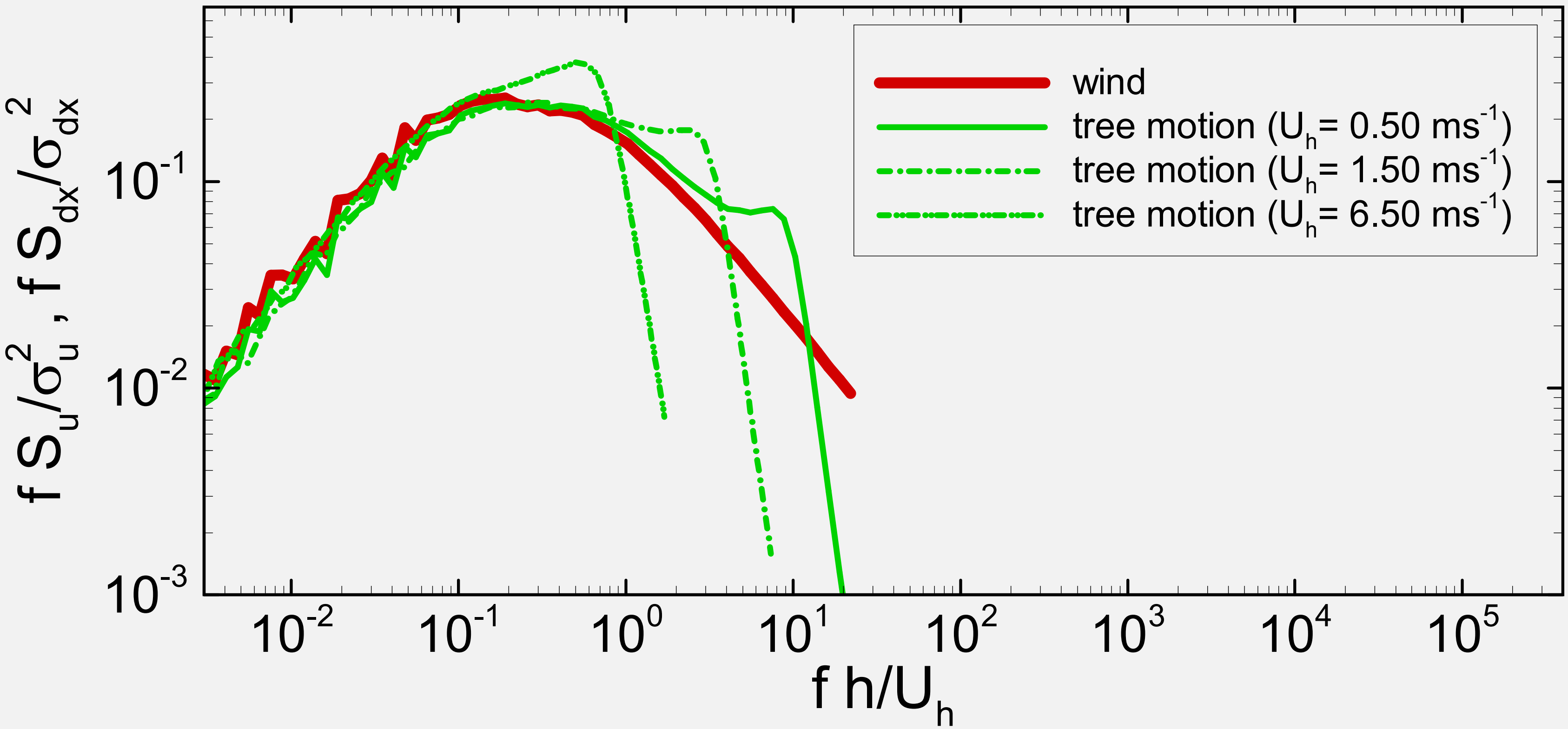
Wind model evaluation: summary

- The wind model retrieves the main characteristics of canopy-top turbulence
- Results obtained by only describing the canopy from its cumulative PAI and its height
- The main hypothesis on the weak dependence of canopy-top normalized wind statistics on wind intensity and canopy morphology is well verified

Impact of storm intensity on damage propagation (Maritime pine)

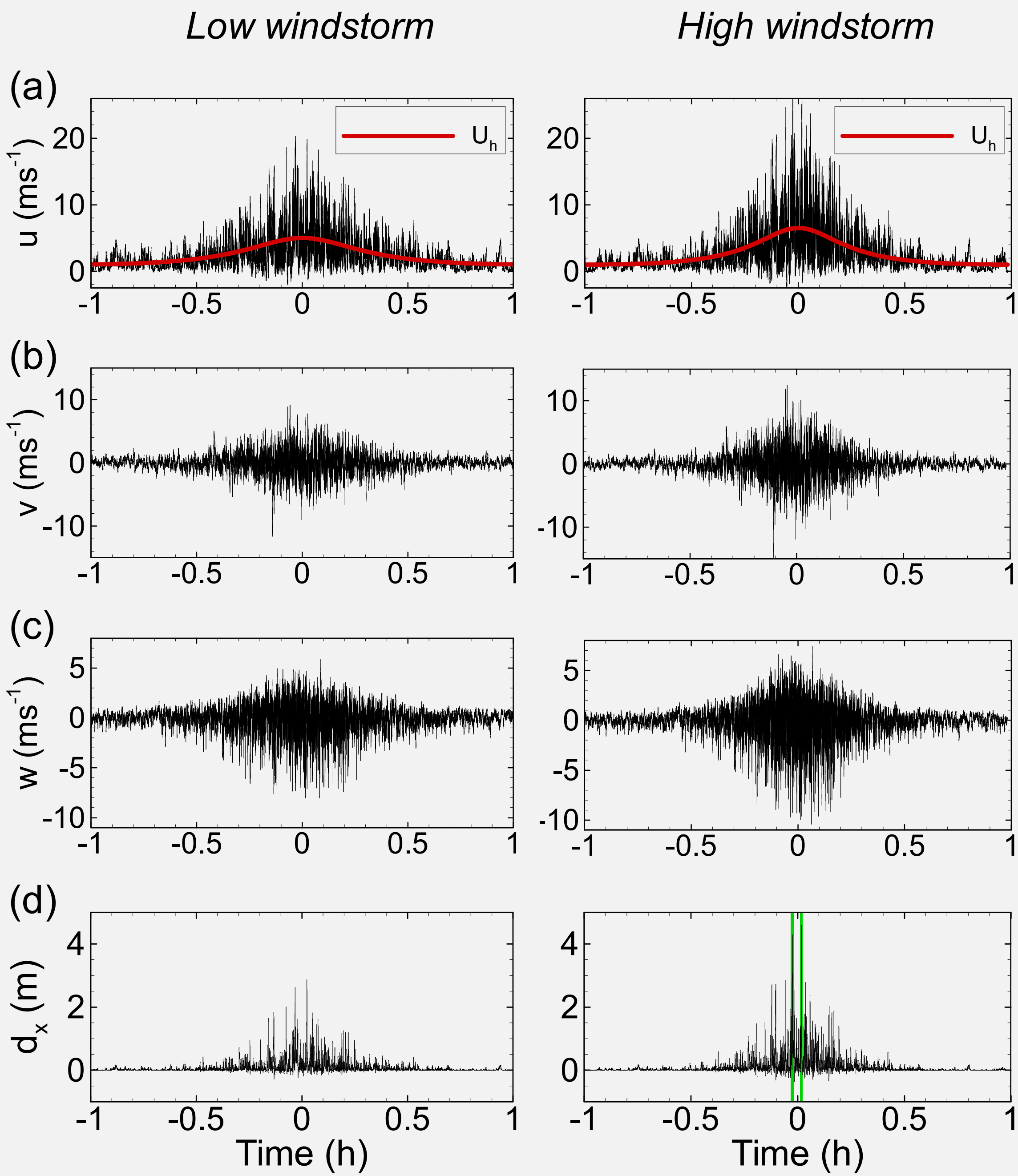


Impact of storm intensity on wind and tree motion spectra (Maritime pine)

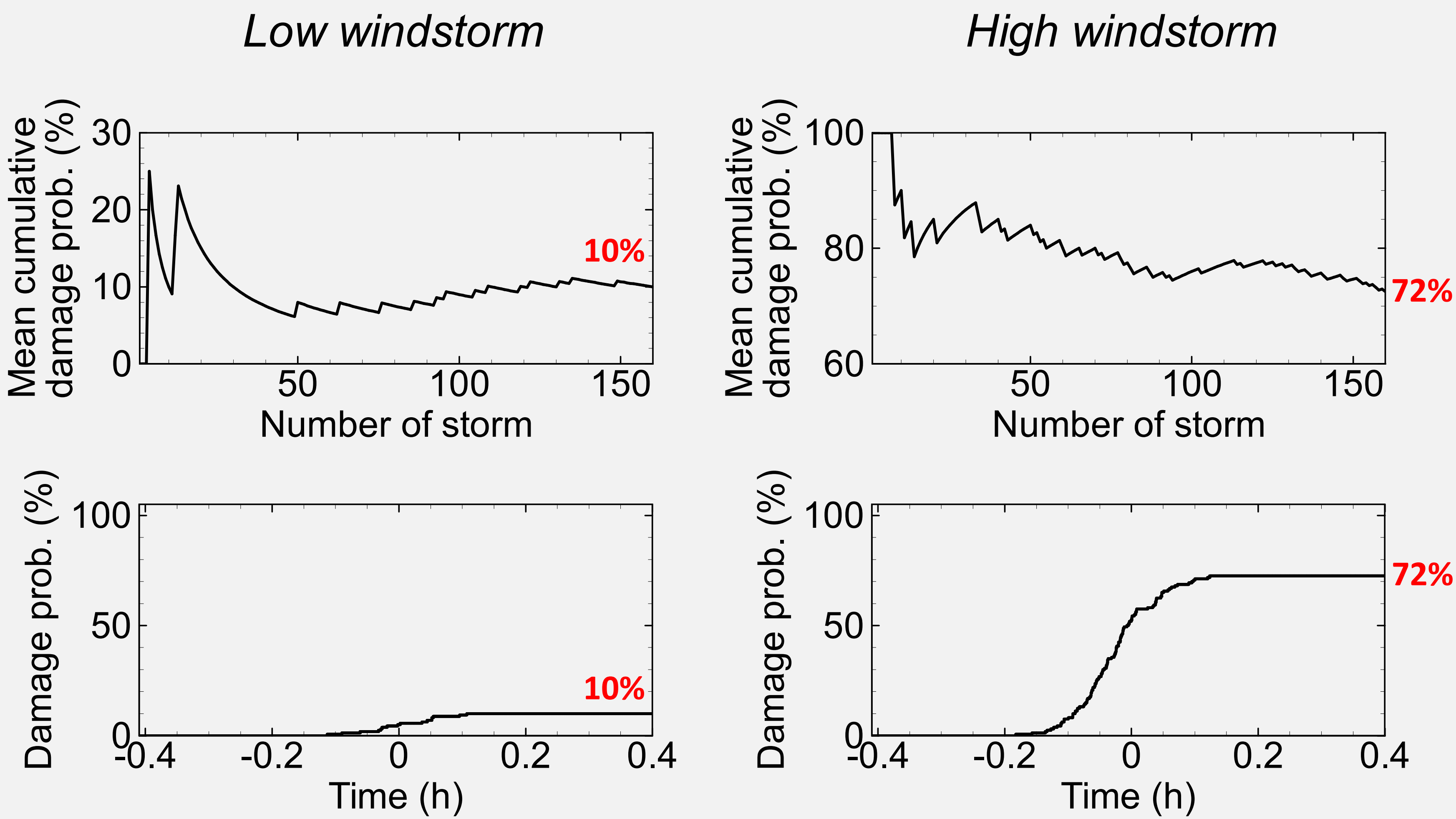


- With increasing wind speed, the tree natural vibration frequency moves upward along the inertial subrange region of the wind spectrum

Damage prediction on a Maritime pine stand



Damage prediction on a Maritime pine stand



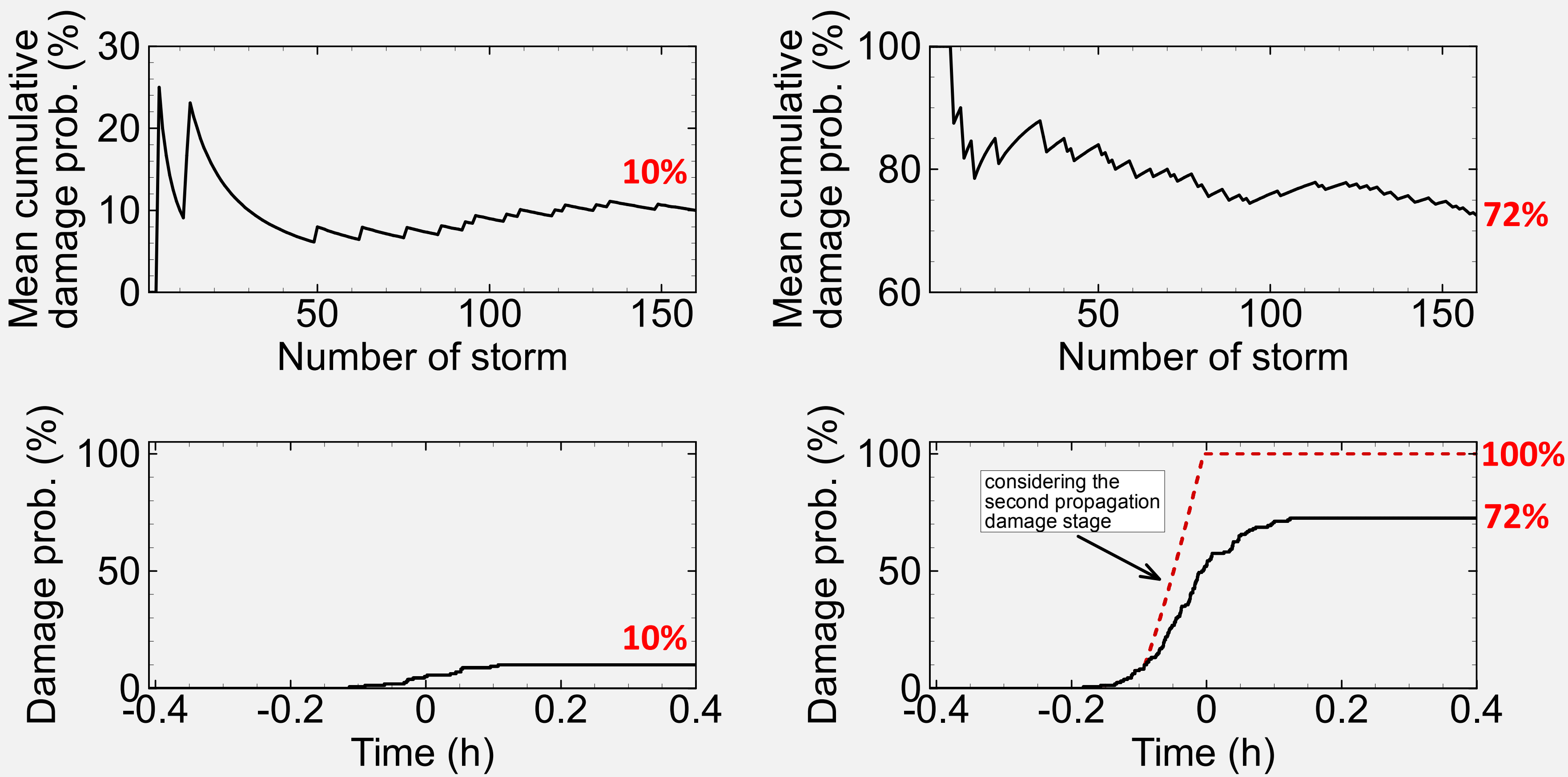
► Without considering the 2nd damage stage

► 2nd damage stage starts when damaged areas reach 10% of the stand (Dupont et al. 2015)

$$v_{prop2} = 4.30\ U_h - 42.71 \text{ (\% of damaged trees/min)}$$

Damage prediction on a Maritime pine stand

Low windstorm *High windstorm*



► Without considering the 2nd damage stage

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$$v_{prop2} = 4.30\,U_h - 42.71 \text{ (\% of damaged trees/min)}$$

Conclusion

Simple wind-tree model:

- ► allowing to easily compare damage prediction between different stands or different storms as well as to investigate the impact of silvicultural practices
- ► answering to several weaknesses of existing wind risk models

More works need to be done to reach a complete wind risk model:

(1) stand heterogeneities: not considered in the present model and poorly accounted for in existing wind risk models (Dupont et al. 2015, *Can. J. For. Res.*)

(2) accentuation of damage propagation when damaged areas become significant enough to modify the wind flow

(3) tree failure due to tree uprooting, not yet considered in the tree swaying model

(4) evaluation of the model against reported damage after windstorms

Thanks for your attention

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