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Notes on combinations and interaction between wind and snow

remarks for discussion at

JCSS Workshop, 2-3 Dec 2024, TU Munich

Time-variant Reliability Analysis: Old challenges and new solutions

M. Sykora

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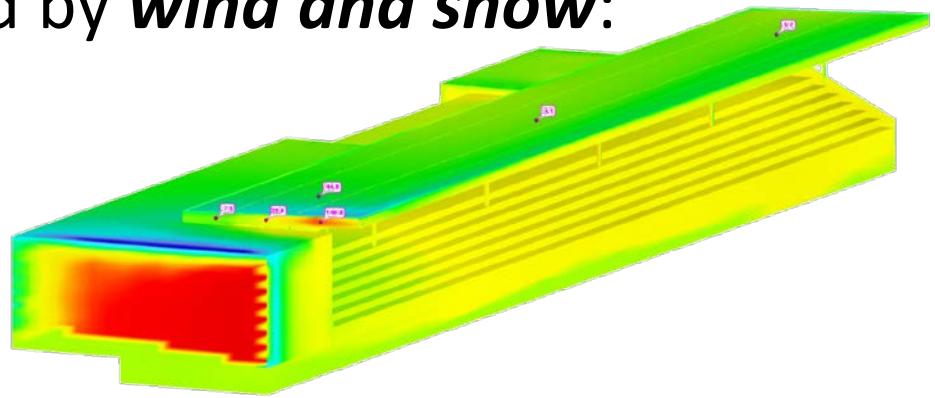
Aims, focus

- Summary of experience related to TV analysis (perhaps better ***modelling of TV loads***)
- Aim to present:
  - achieved findings (generalisation?)
  - open issues (get feedback, trigger discussions)
- Focus on structures whose reliability is dominated by ***wind and snow***:
  - lightweight (implicitly focusing on steel)
  - quasi-static loads
  - ergodic and stationary cases (no discussion on climate change and on degradation)
  - ULS (low failure probabilities)



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Structure

1) Load combinations
   - calibrations
   - ‘all’ structures – ‘common’ situations
2) Interaction of loads
   - snow affected by wind, T, etc.
   - type of structure such as flat roof
3) Modelling of individual loads – selected issues
   - wind load
   - snow load

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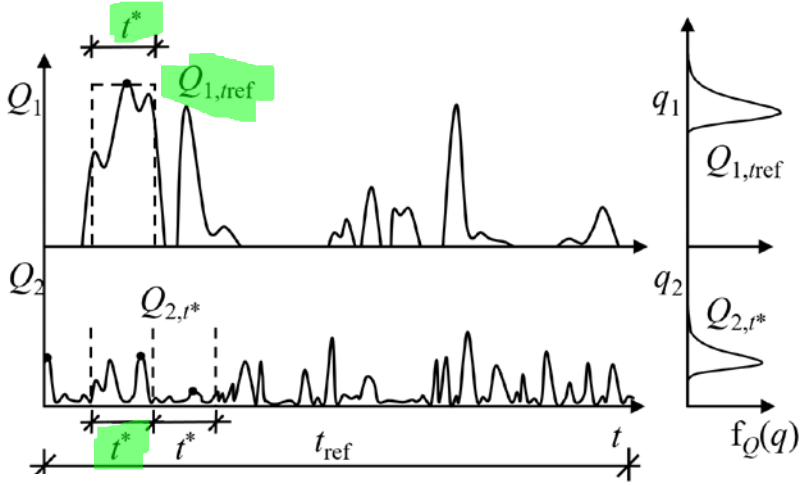
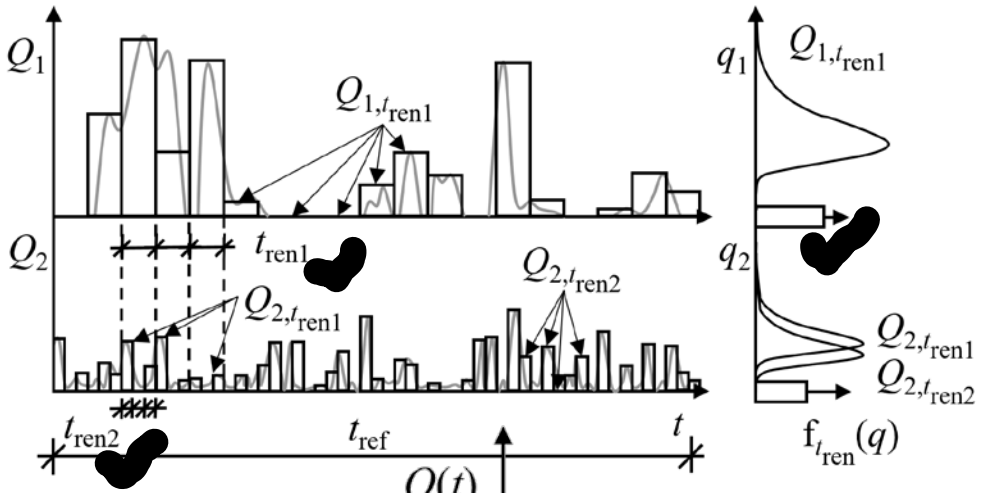
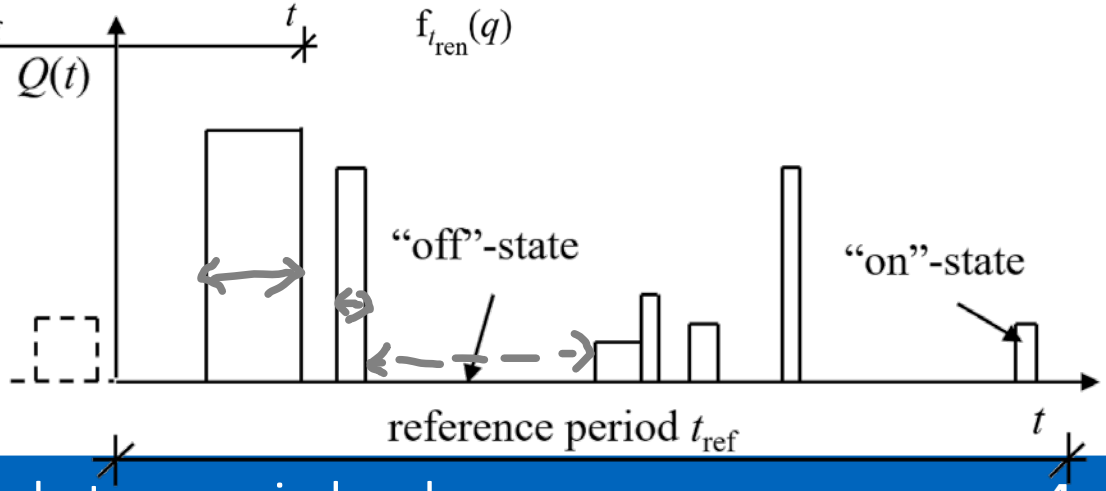
1) LOAD COMBINATIONS

Wind and snow combination described by:

- Turkstra's rule (leading wind/ snow)
  - in principle does not provide upper bound on P_f (unless 'conservatively' applied?)
- FBC models (Ferry Borges and Castanheta)
  - rectangular wave renewal processes with fixed durations of pulses
  - often believed to provide good estimate of max of combined load effect
- RWR processes with random durations (Rackwitz)
  - 'renewal' processes
  - upper bound on failure probability







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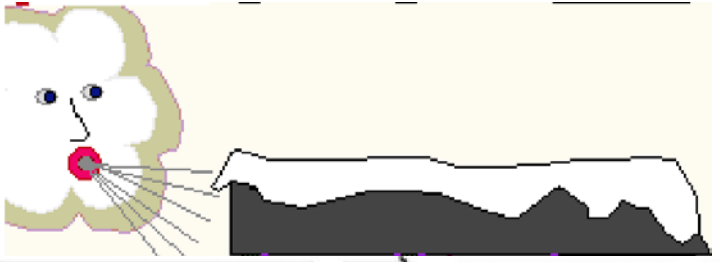
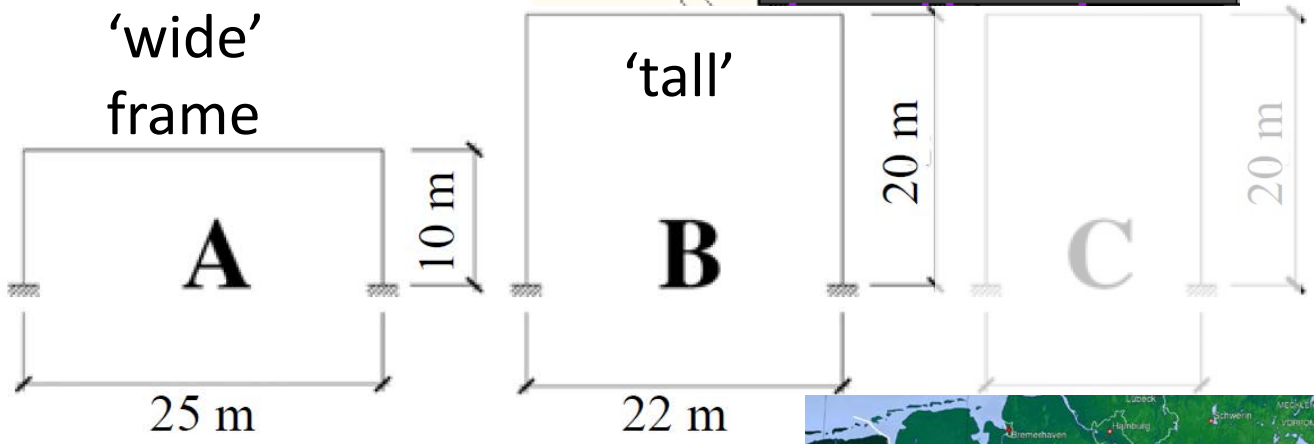
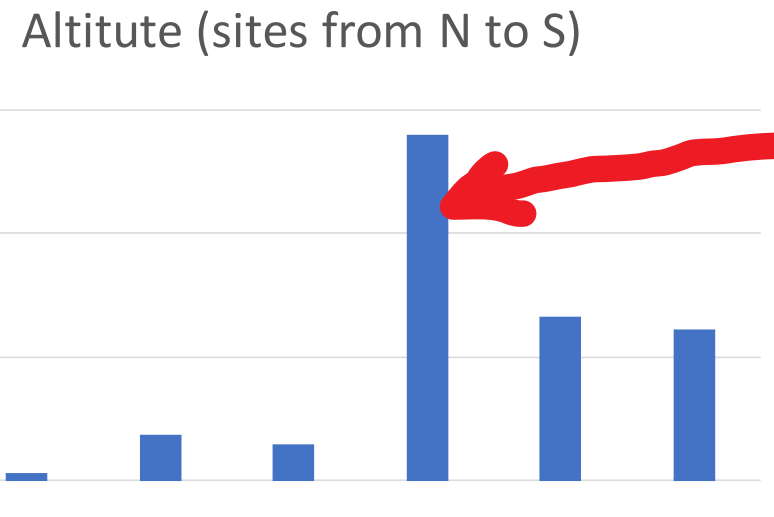
Numerical illustration





- Steel frames
- Six locations in Germany
- Monthly maxima of wind and snow loads
  - 'on'-probabilities for snow



Sykora & Holicky. Comparison of load combination models for probabilistic calibrations, ICASP11

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Reliability analysis

- g[**X**(t)] = $K_R R$ - K_E[G + $S(t)$ + $W(t)$], reference period – 50 years
- Turkstra – e.g. for dominating snow:
  - for continental climate 50y max of snow assumed to last one week
  - weekly max of wind should considered – monthly max conservatively applied
- FBC: fixed duration one month for both S+W
- Renewal processes:
  - 3-6 snow events per year
  - 12 wind storms of short duration

Variable	Dist.	μ_X/x_k	V_X	$p_{on,X}$
Resistance R	LN	1.18	0.08	-
Permanent load G	N	1	0.10	-
Snow on roof S (Münster)	GU	0.26	1.17	0.23
Wind action W (Münster)	GU	0.17	0.67	1
Resistance uncertainty K_R	LN	1.15	0.05	-
Load effect uncertainty K_E	LN	1.0	0.10	-

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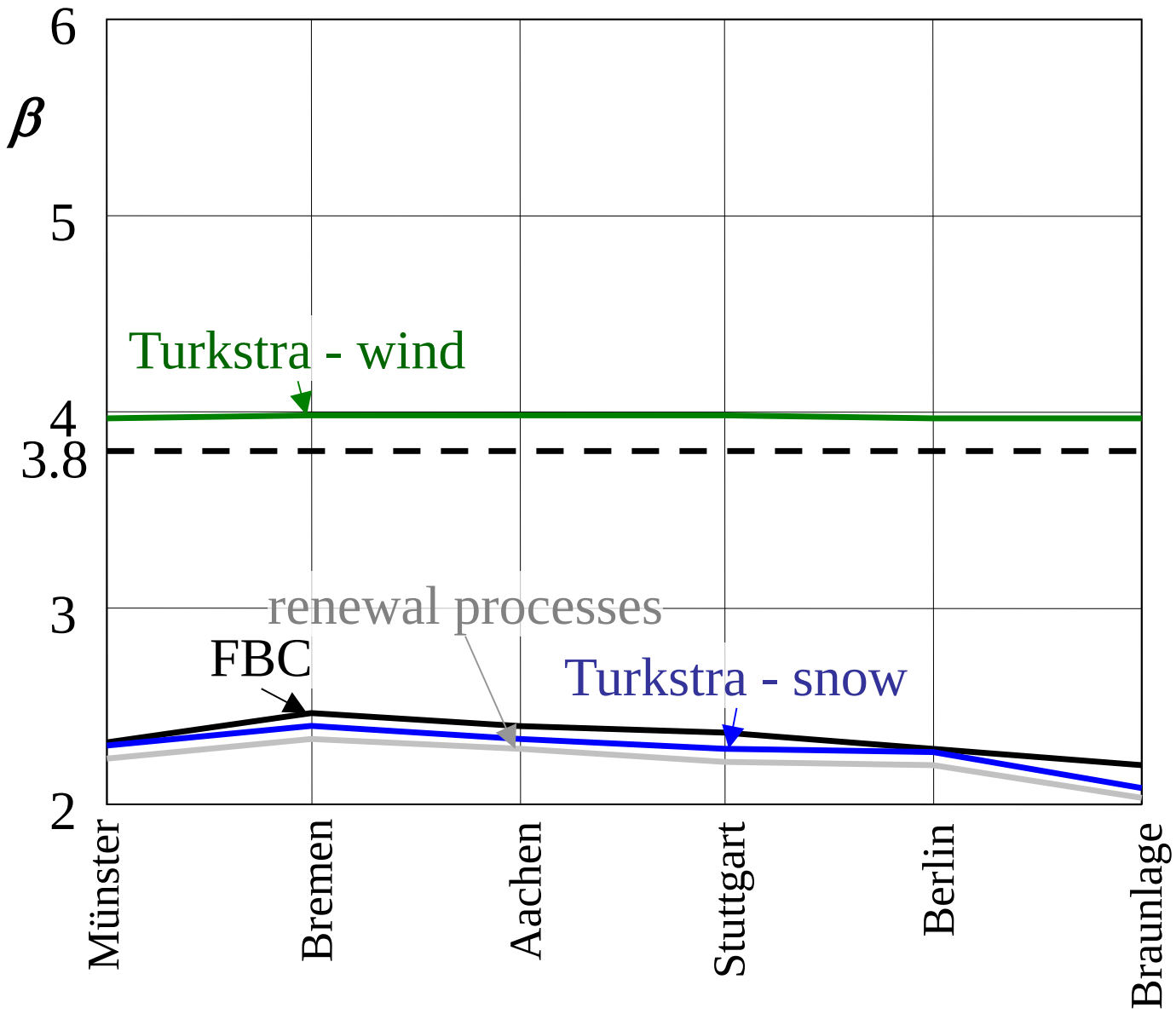
Reliability index – wide frame

- Snow dominant
  - frame C – wind

→ insignificant differences between approaches √



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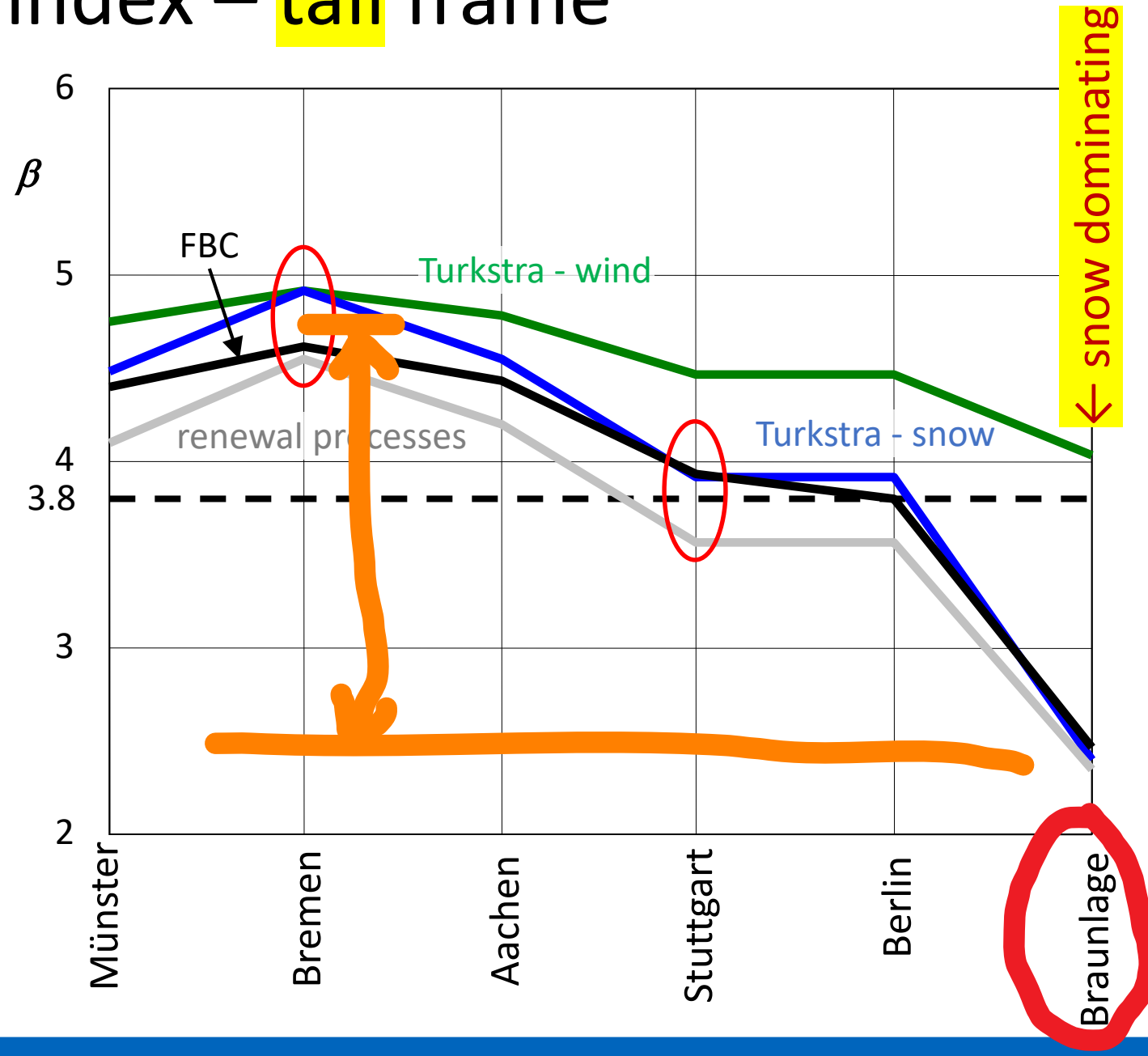
Reliability index – tall frame

- Snow and wind – similar effects

→ Turkstra seems unsafe when truly E(S,w) ≈ E(s,W) ×

→ there is no clear reference solution in this simplified case

→ local aspects might be more important



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LOAD COMBINATIONS – summary

- Applicability of reliability methods ('common' softwares)
  - Turkstra - any of well-established methods for time-invariant analysis √
    - often gives good first estimate
  - FBC and renewal processes:
    - some further considerations needed x
    - potential for easier (slightly more user-independent) applications in SW? (cases with a number of TV loads)
- Accuracy
  - Turkstra – sufficiently accurate in most cases
    - given the rule is 'reasonably' applied
  - FBC models – could be close to 'exact' solution
    - applicability to short-term actions like wind storms and earthquakes disputable
  - Renewal processes – applicable for many types of actions
    - crude approximation by upper bound when time-invariant variables dominate

Perfect load combination approach based on imperfect models of TV loads?

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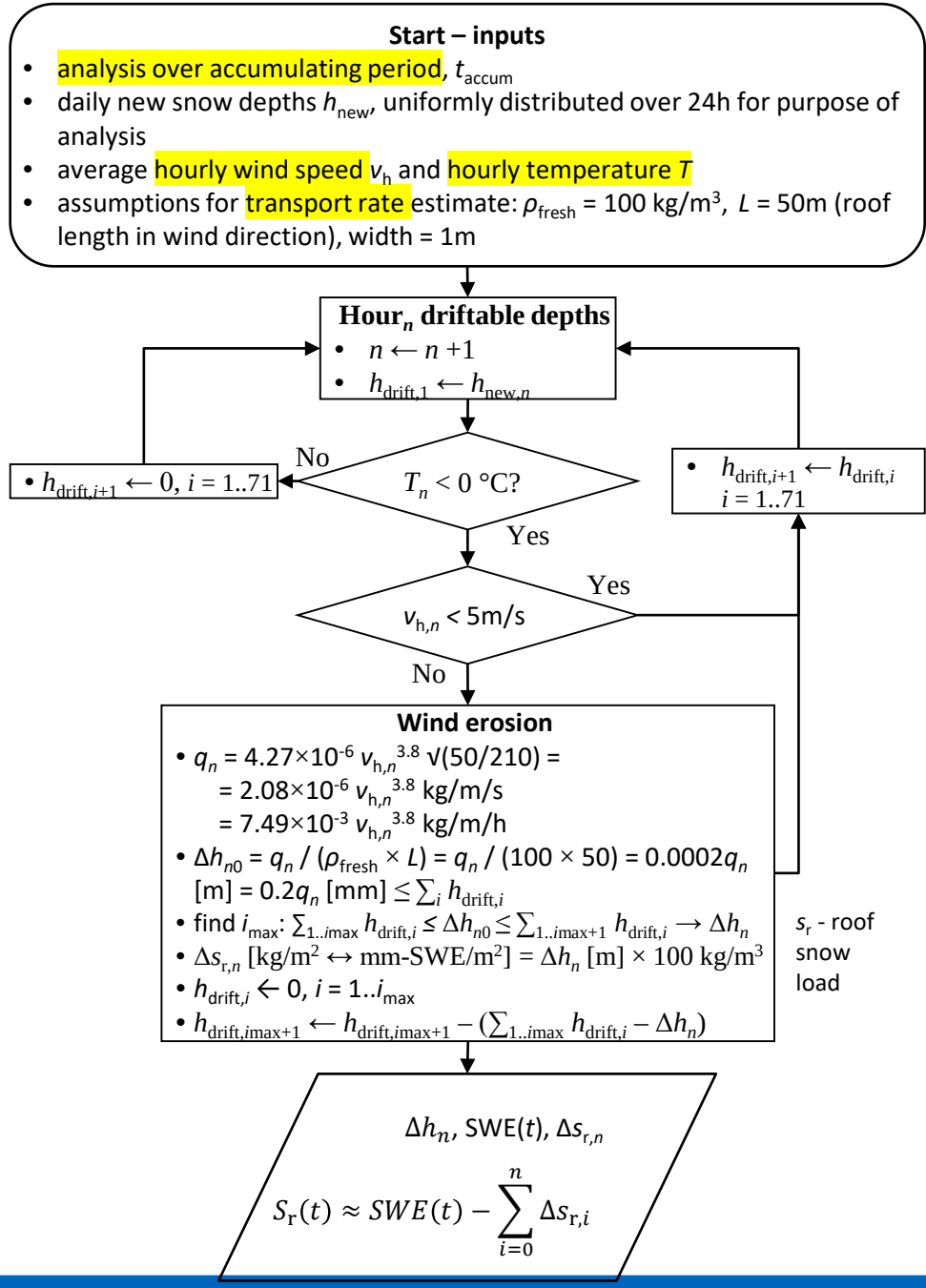
2) Physical INTERACTION of TV loads

- Illustration for snow load on flat roof
  - affected by snowfall pattern, wind in cold season, ambient air temperature, etc.
  - effects related to 'exposure coefficient' only (thermal coefficient disregarded)
- Simplified approach presented



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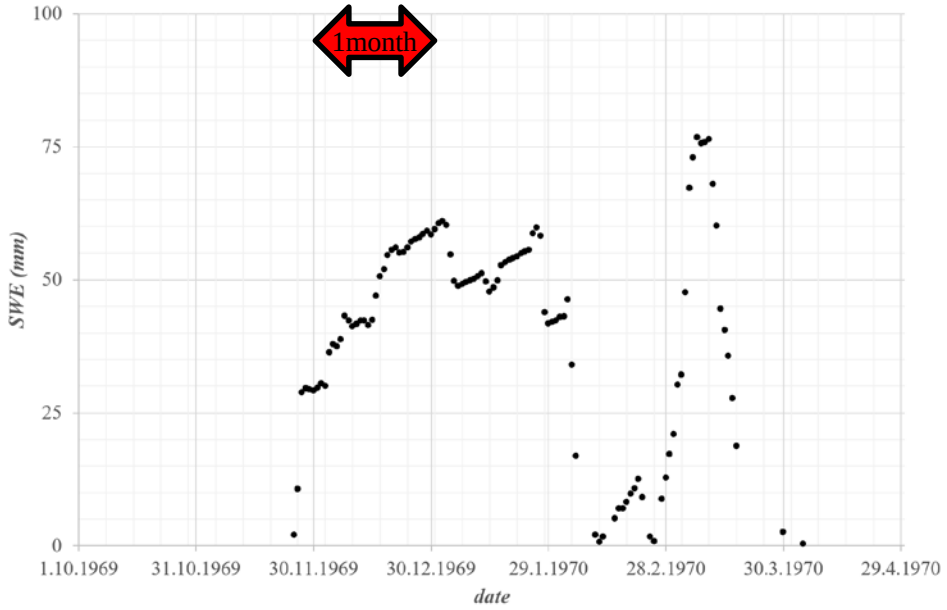
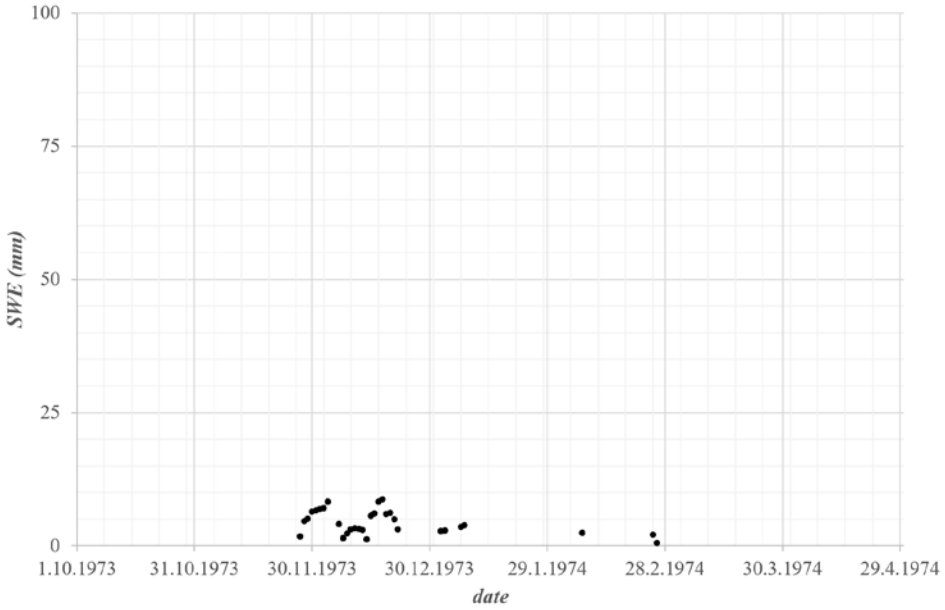
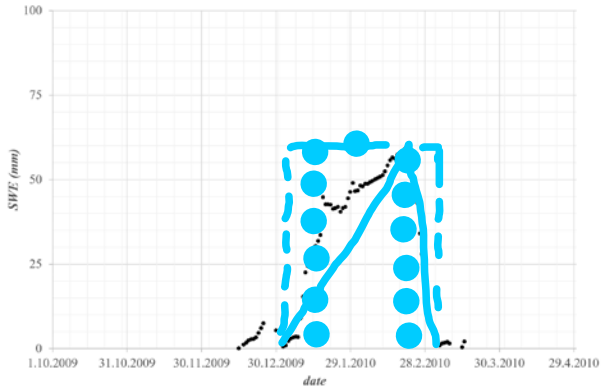
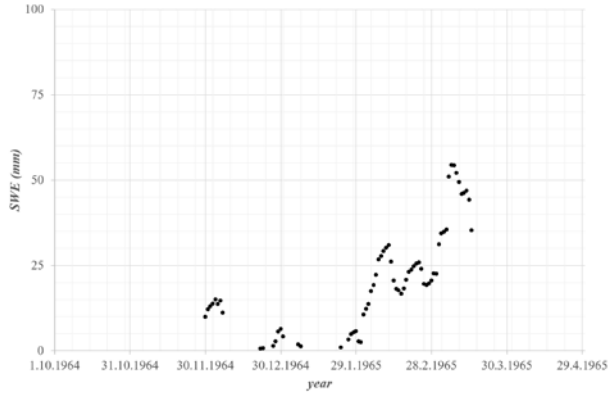
Accumulating period

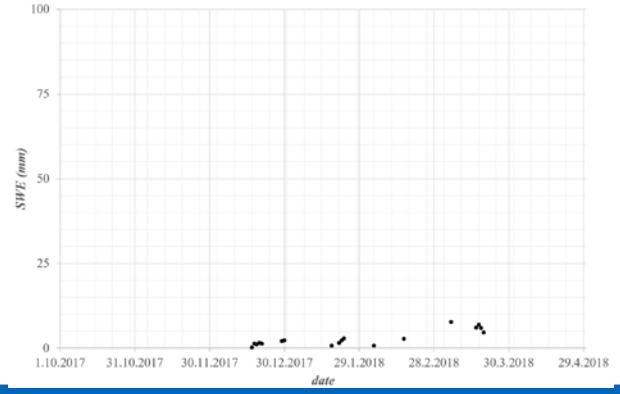
- example for station in Prague – wide range of conditions











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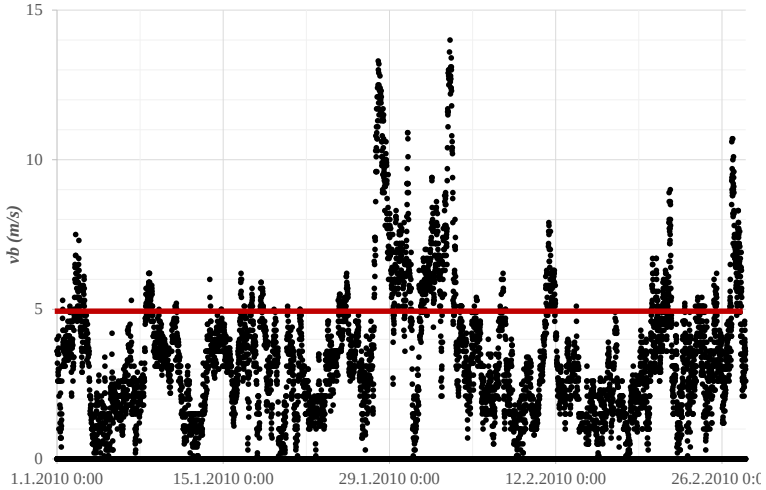
Wind speed and temperature during accumulating period

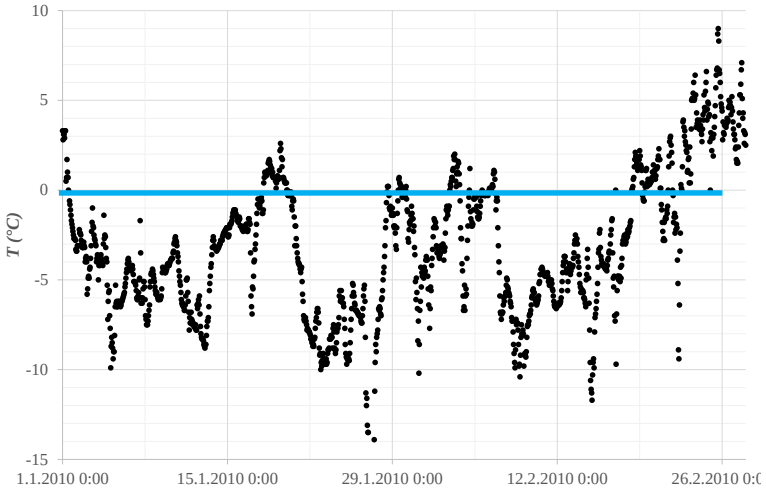
- large uncertainty in effects of these factors



observed →

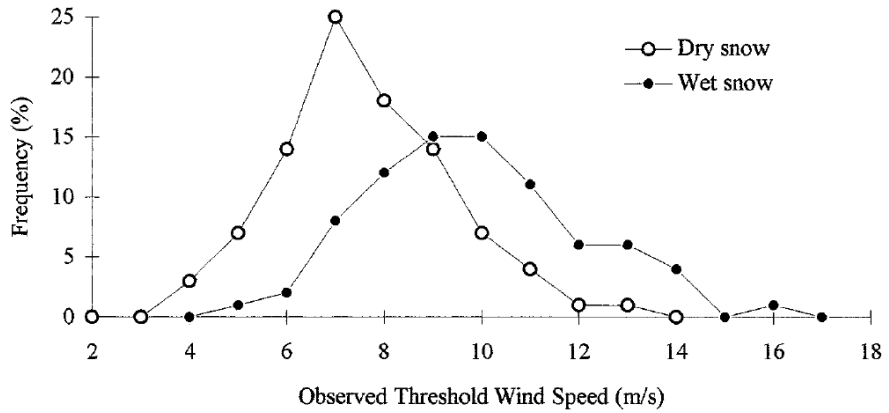
threshold speed

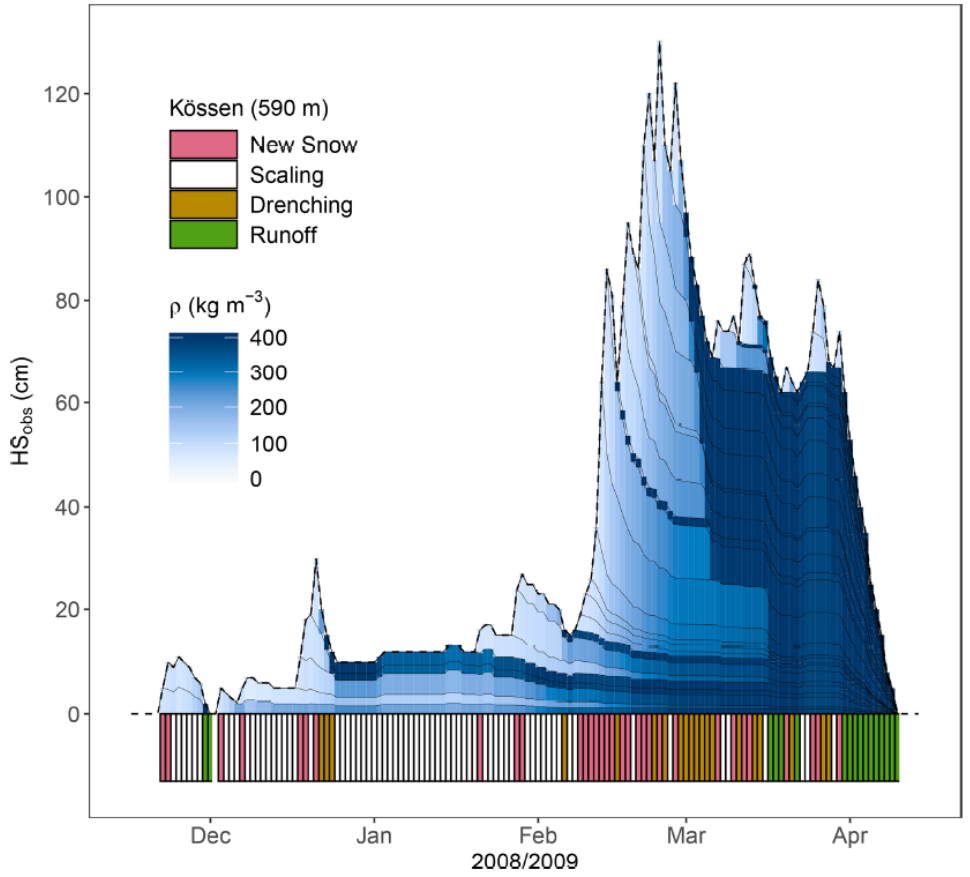
← actual wind speed



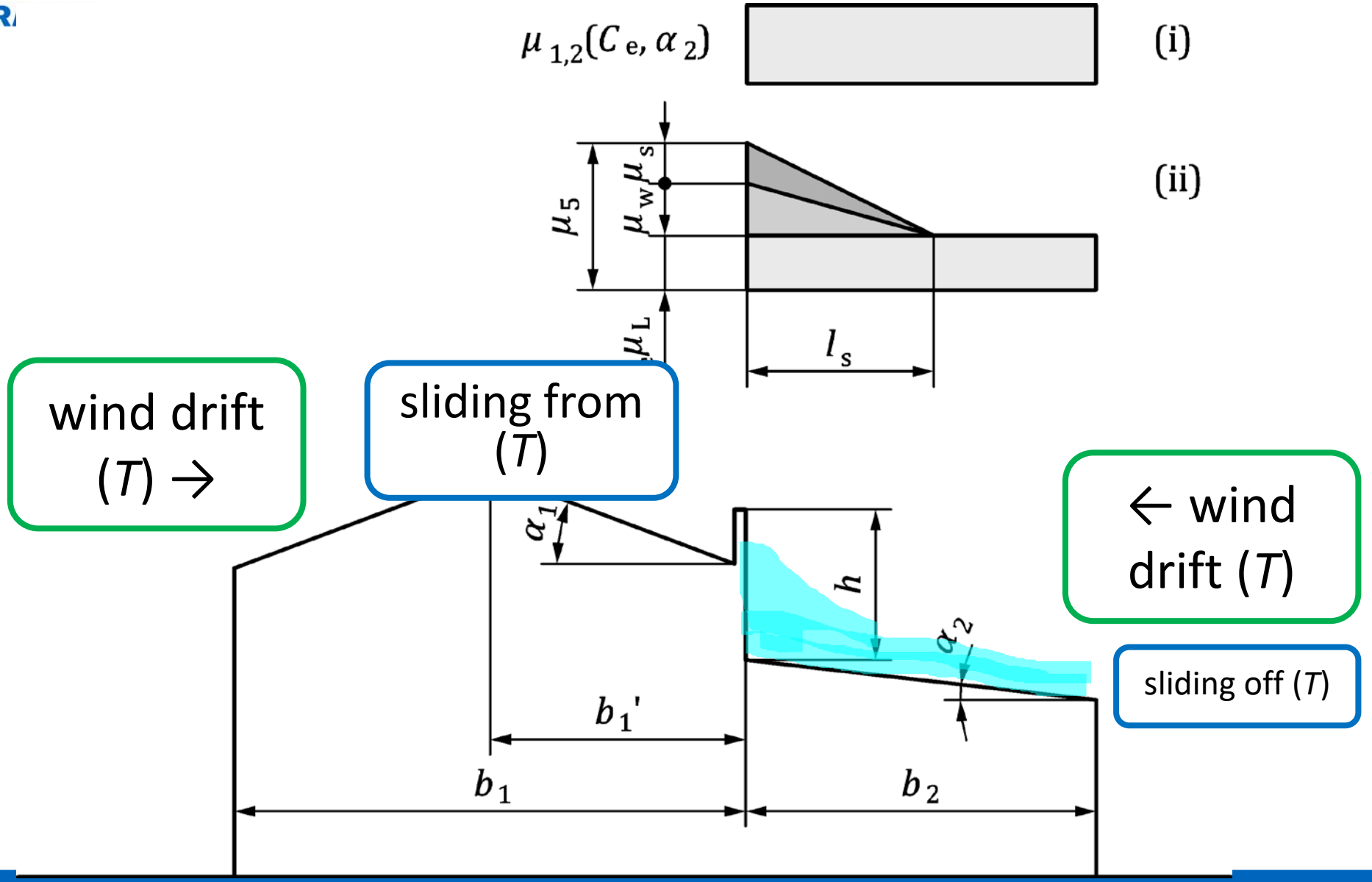
← air temperature

snow density (*T*,*t*) →





Roof abutting to taller buildings



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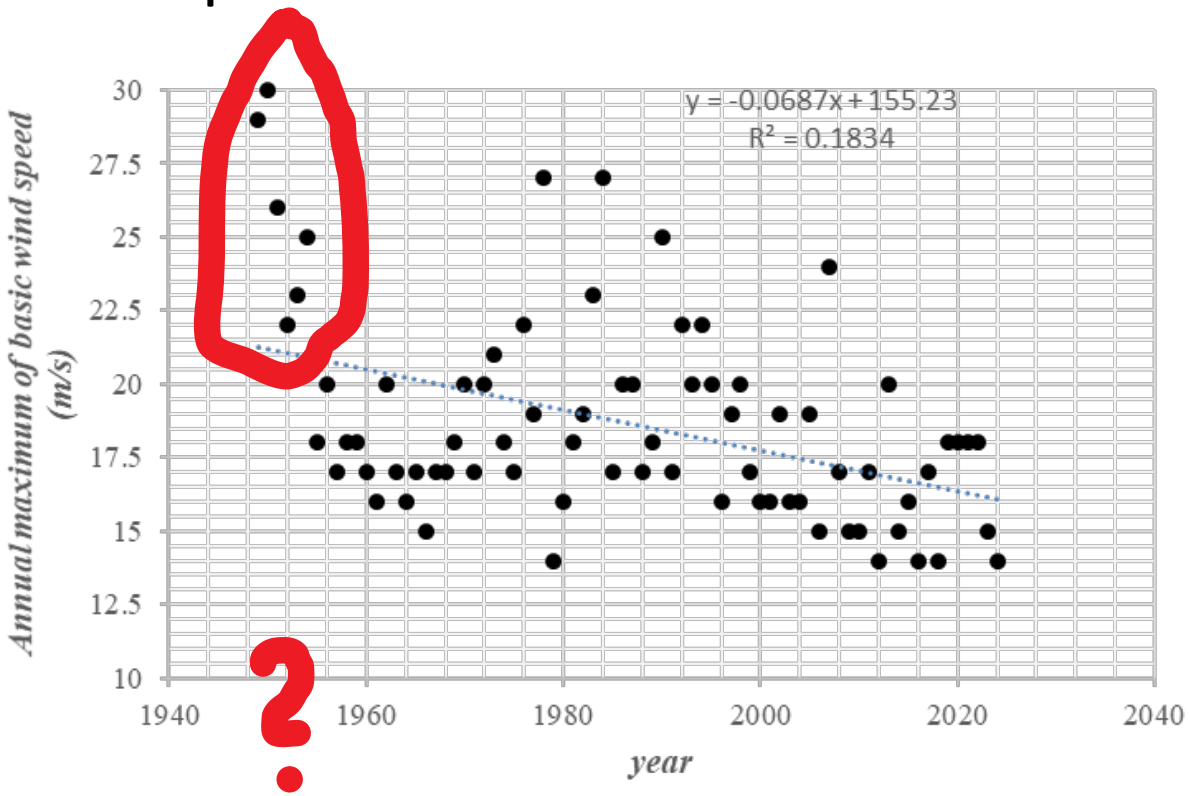
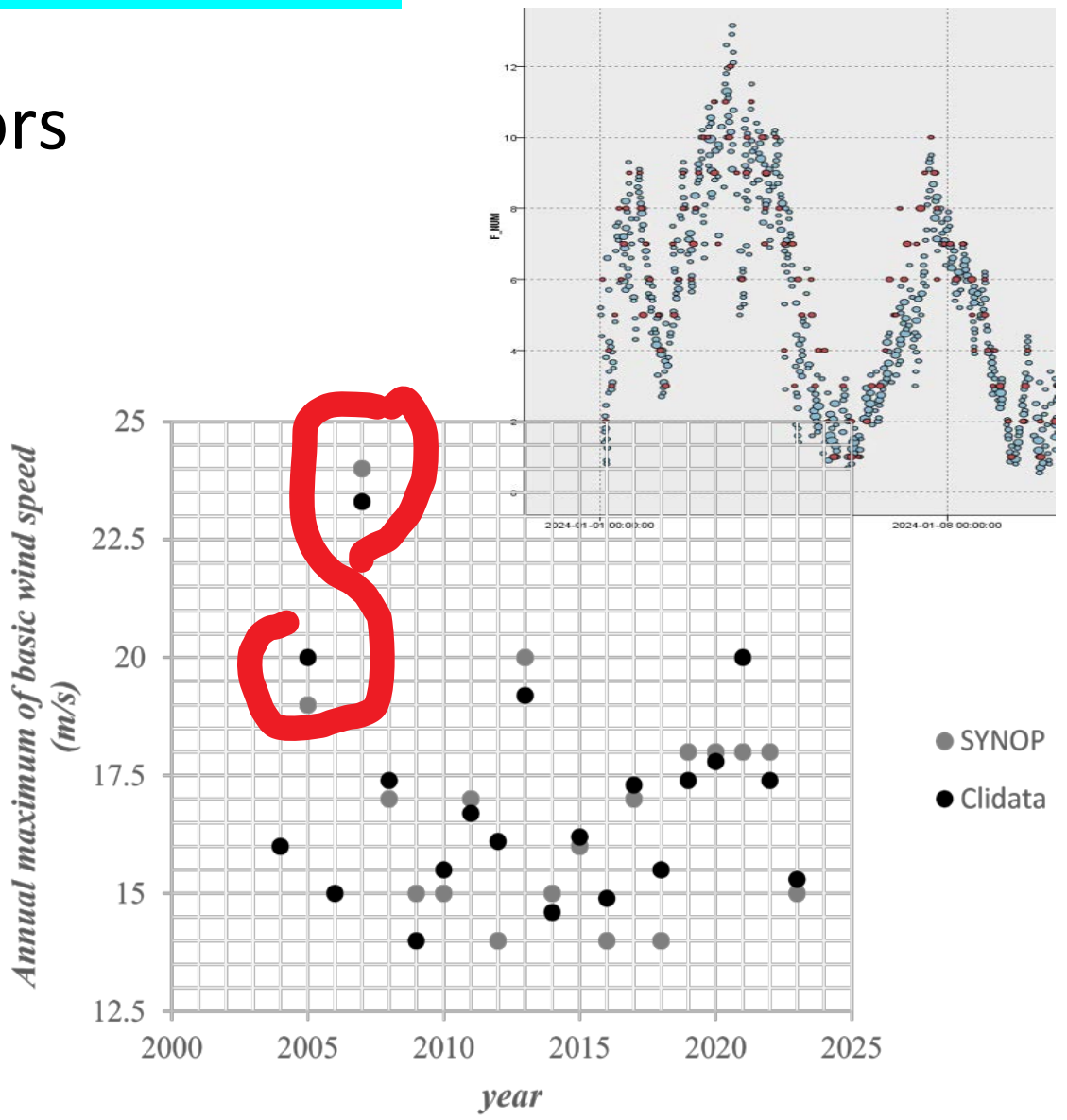
3) Modelling of individual loads – selected issues

- wind - measurement uncertainty, errors
  - issues with location and anemometers
  - experience from one station





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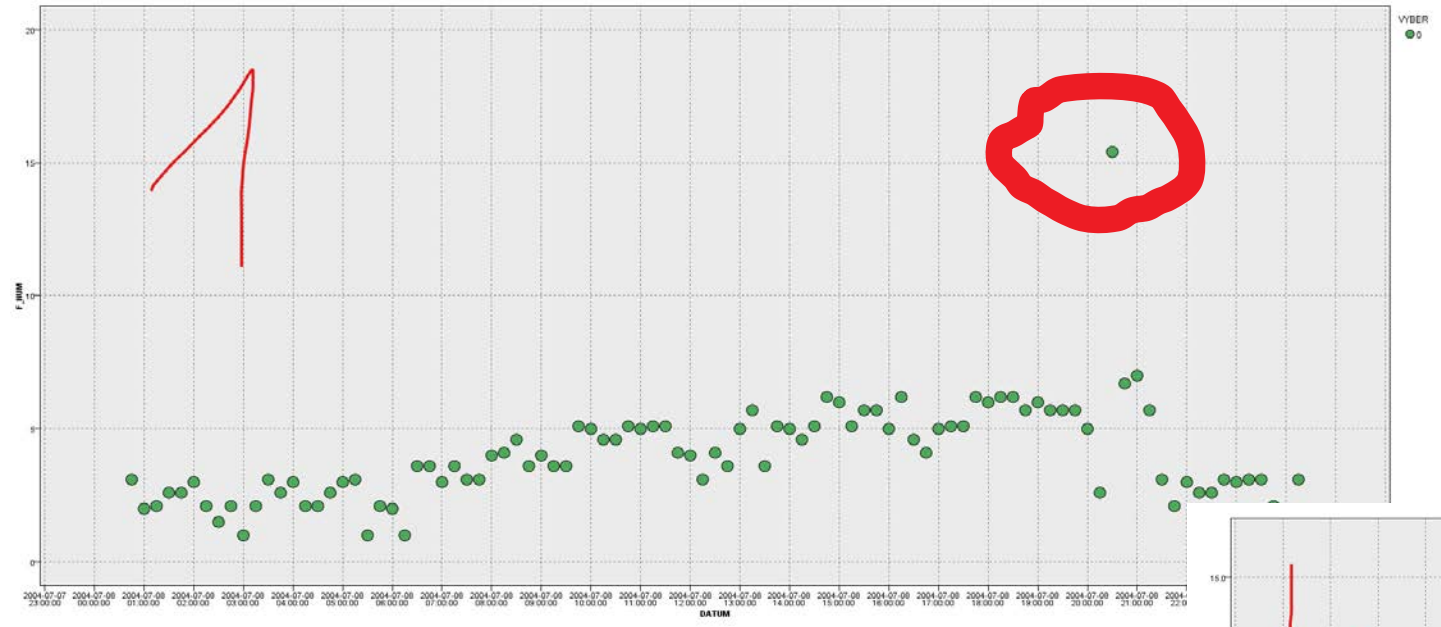
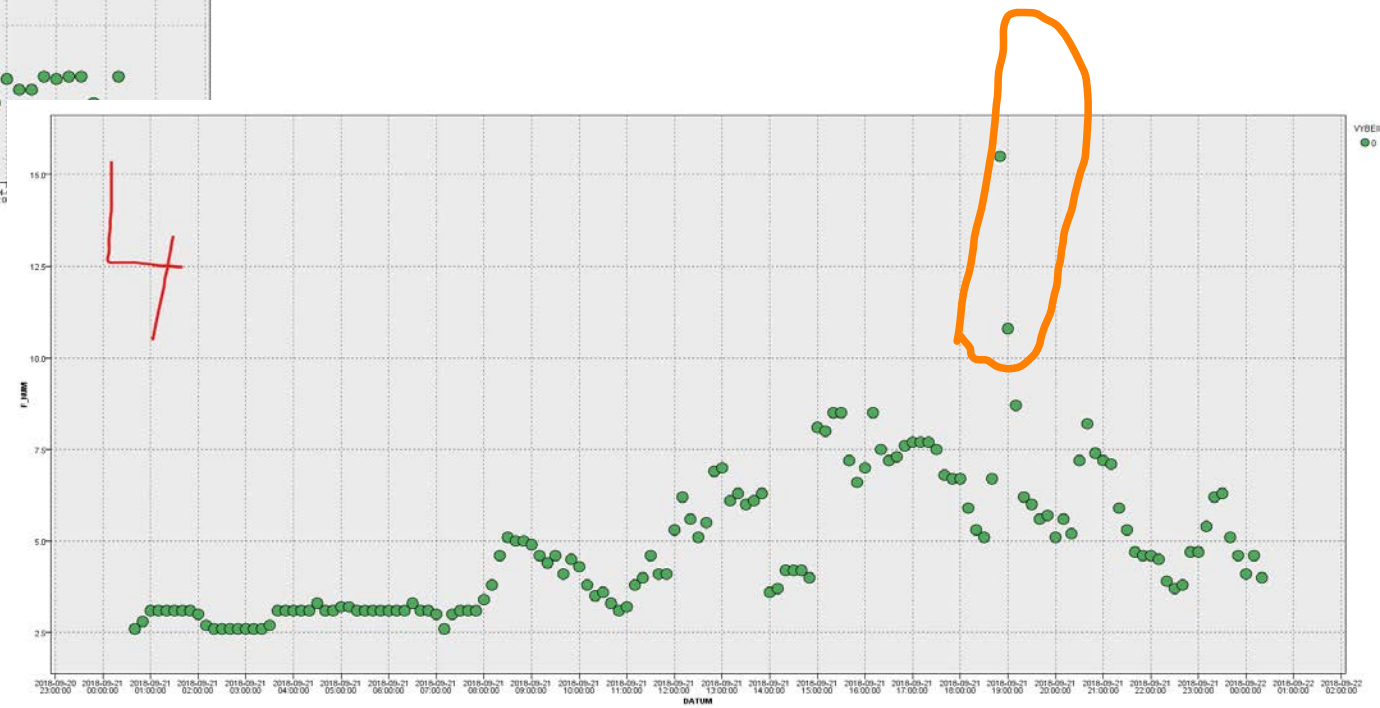
Issues – wind





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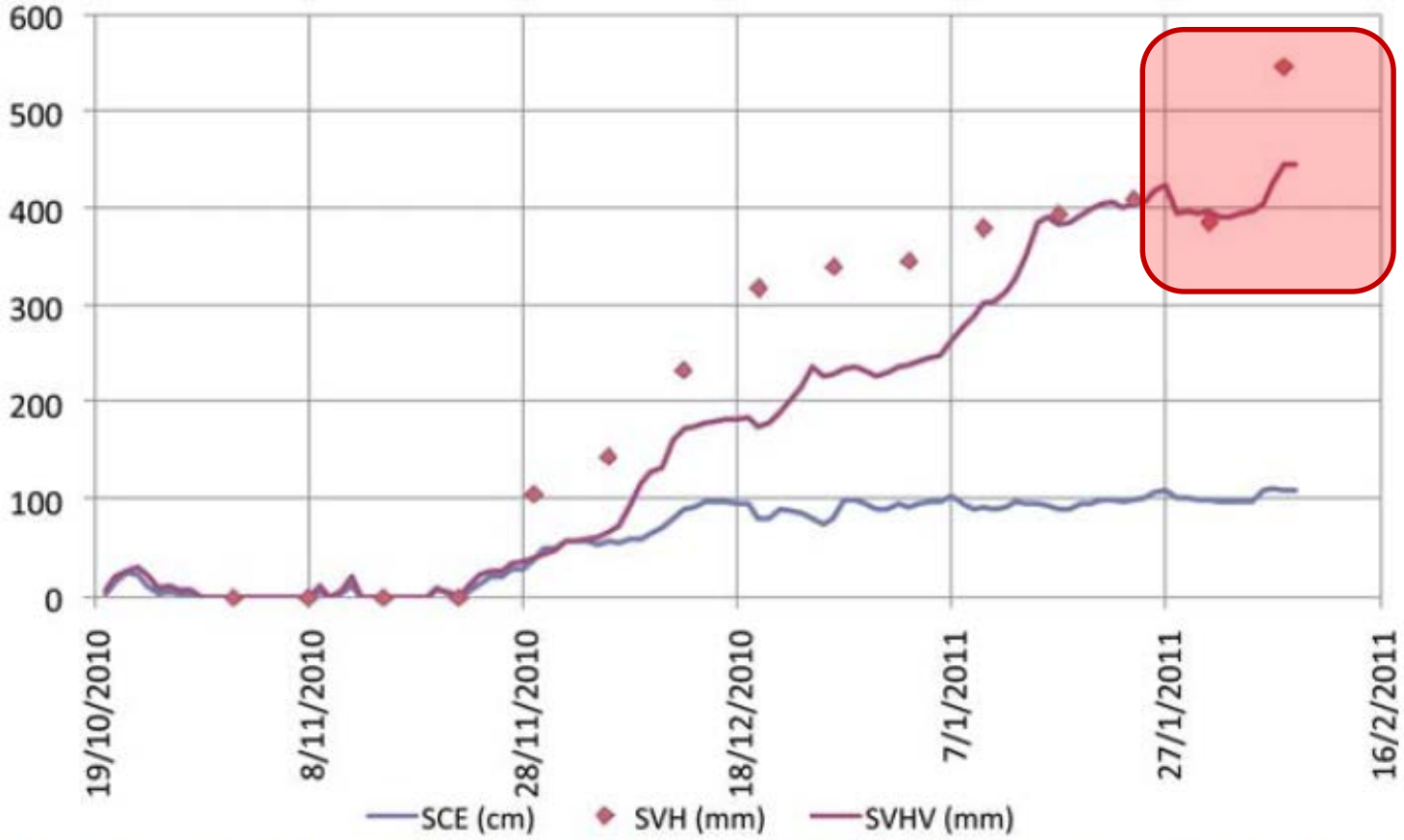
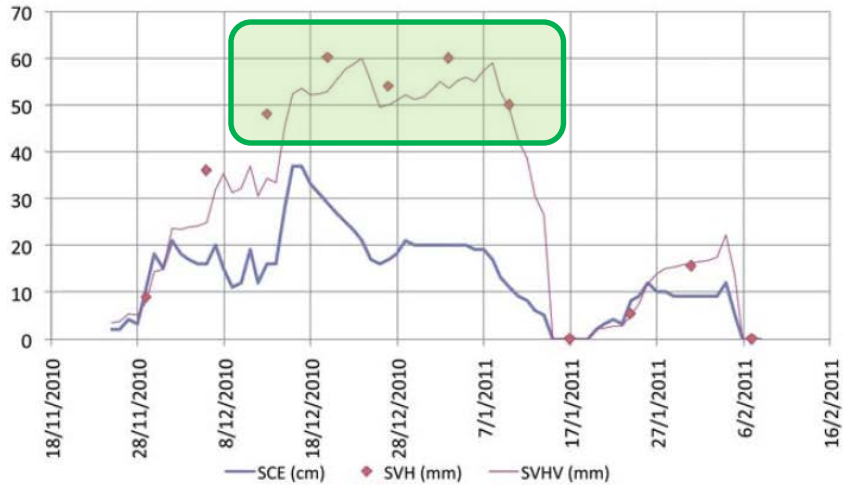
Issues – snow

- calculated and measured values

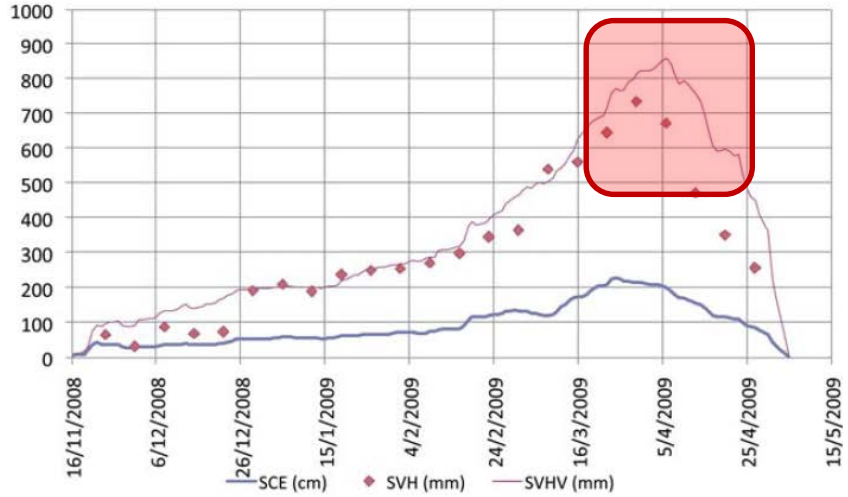


Obr. 4 Stanice Špindlerův Mlýn, Labská bouda, výška a vodní hodnota sněhové pokrývky, sezona 2010/2011.



Obr. 2 Stanice Ondřejov, výška a vodní hodnota sněhové pokrývky, sezona 2010/2011.

Fig. 2. Ondřejov station, snow depth and snow water content, season 2010/2011.



Obr. 3 Stanice Špindlerův Mlýn, Labská bouda, výška a vodní hodnota sněhové pokrývky, sezona 2008/2009.

Fig. 3. Špindlerův Mlýn and Labská bouda stations, snow depth and snow water content, season 2008/2009.

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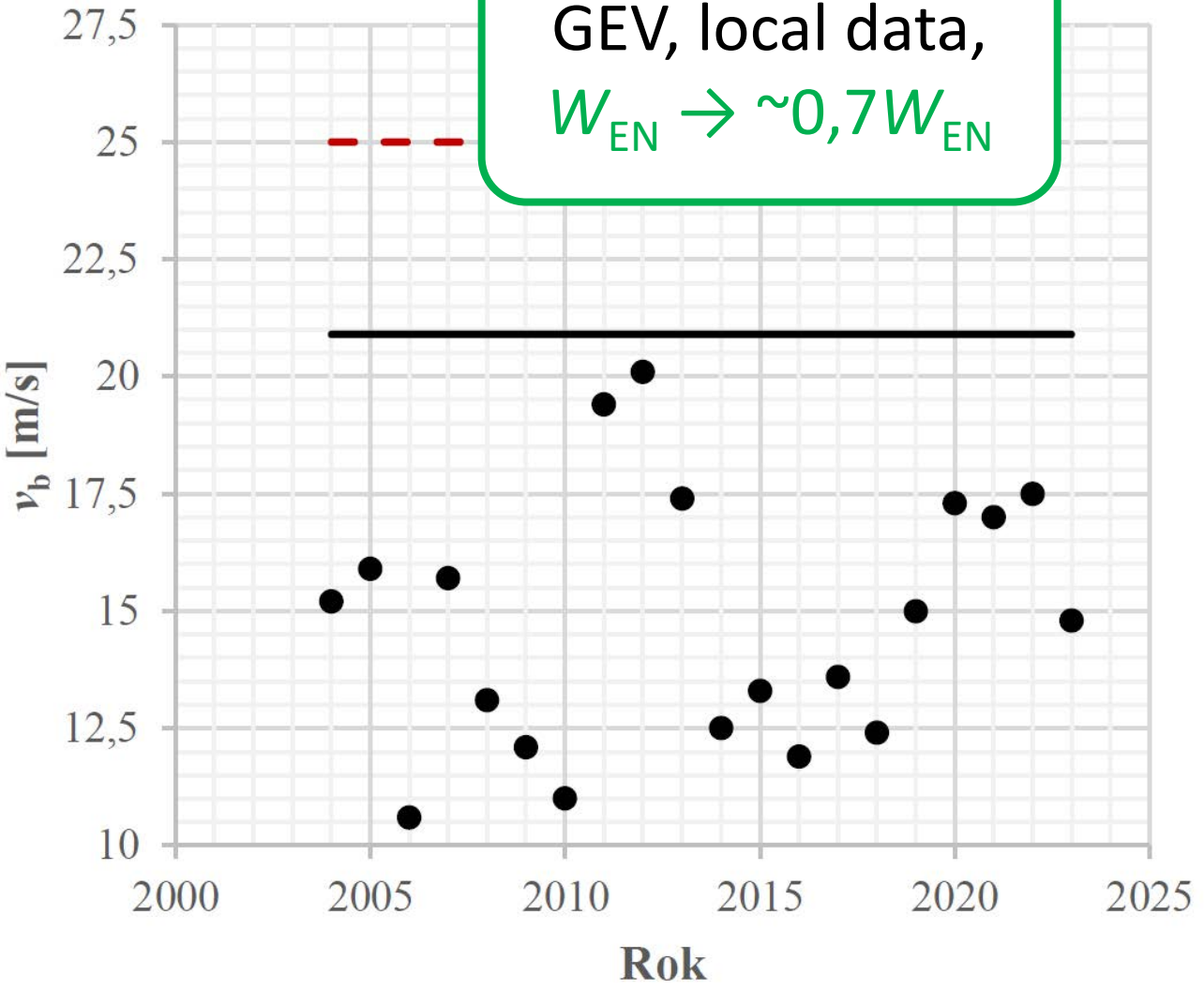
Hidden safety – wind – existing roof of grandstand – statistical evaluation of records

GEV, local data,
$W_{EN} \rightarrow \sim 0{,}7 W_{EN}$



Hidden safety – orography

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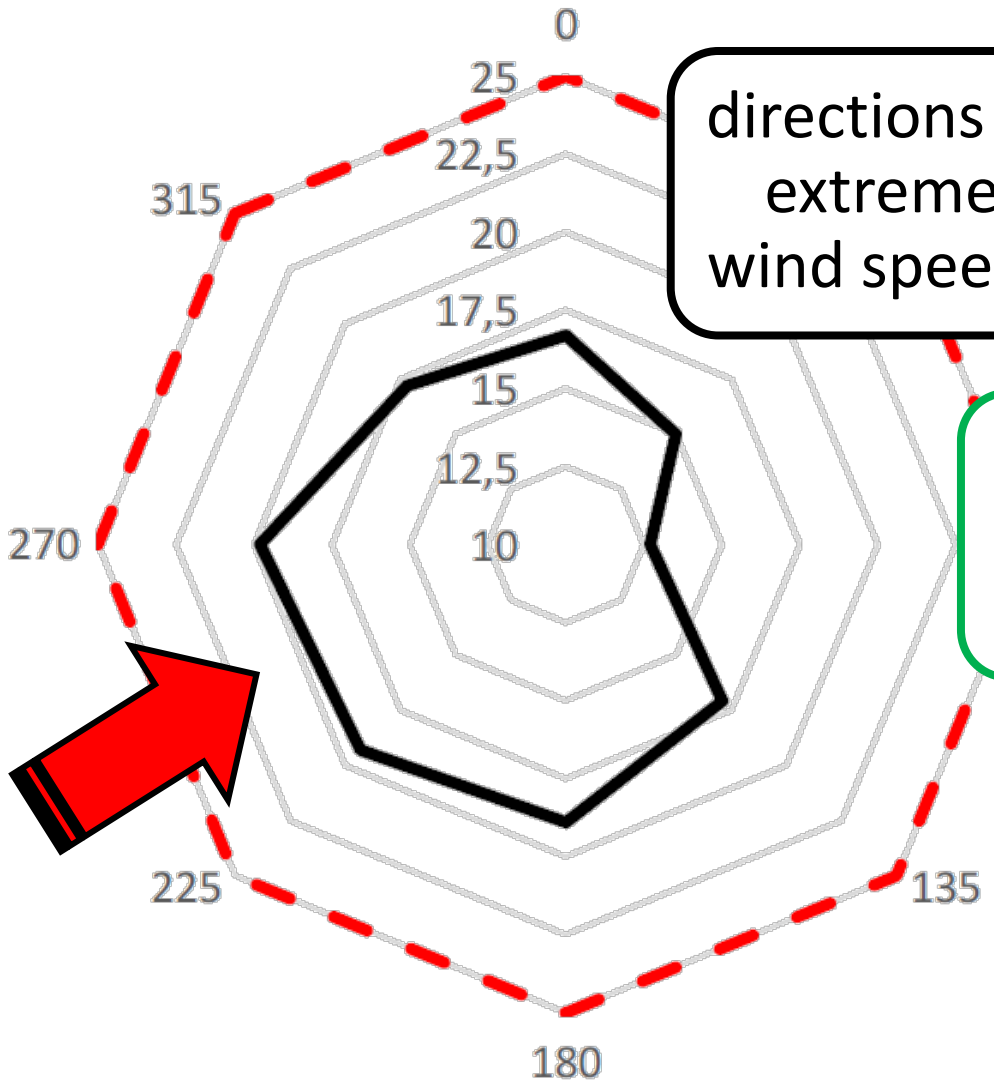
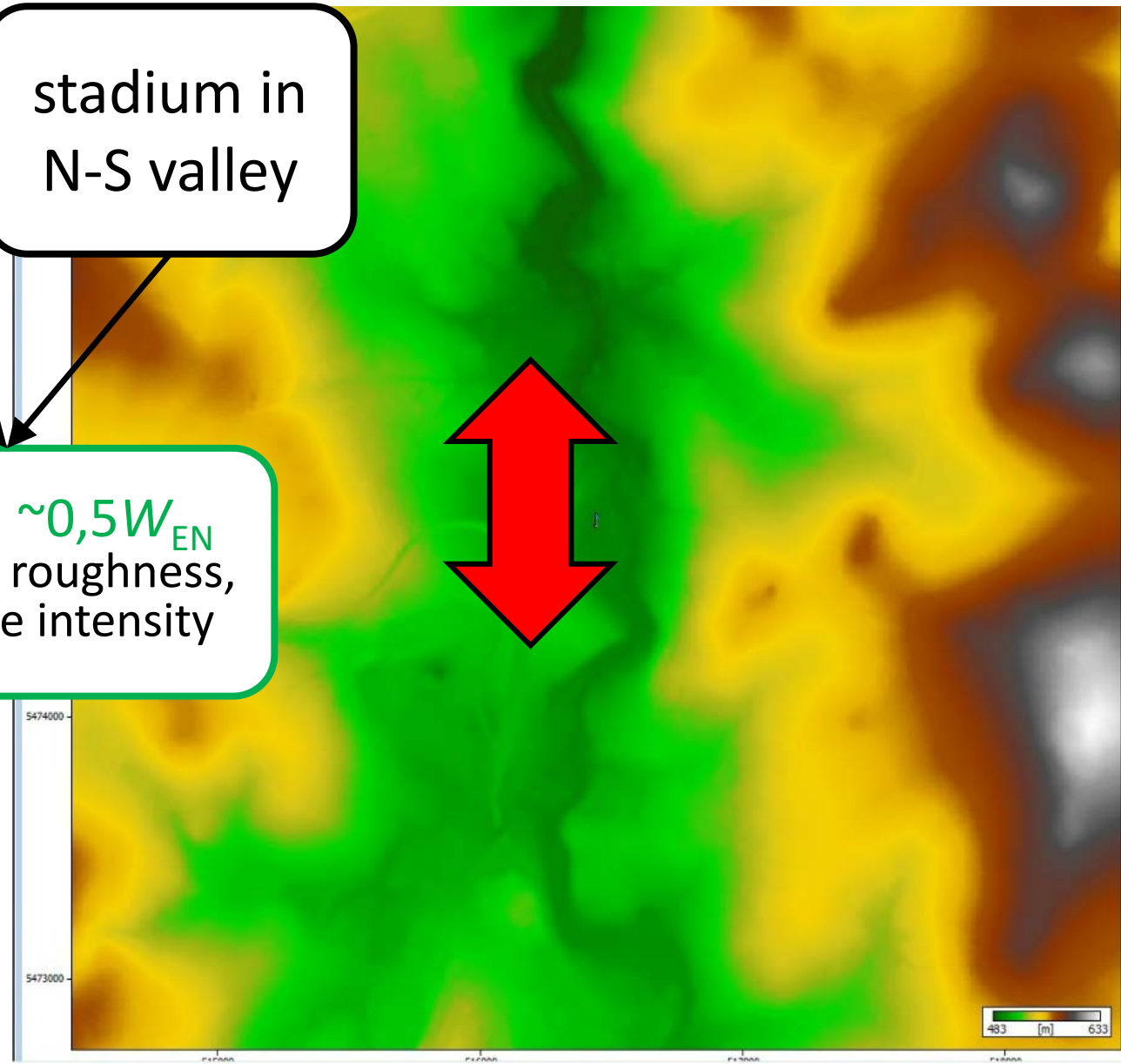


directions of extreme wind speeds

stadium in N-S valley

$\sim 0{,}7 W_{EN} \rightarrow \sim 0{,}5 W_{EN}$
orography, roughness, turbulence intensity



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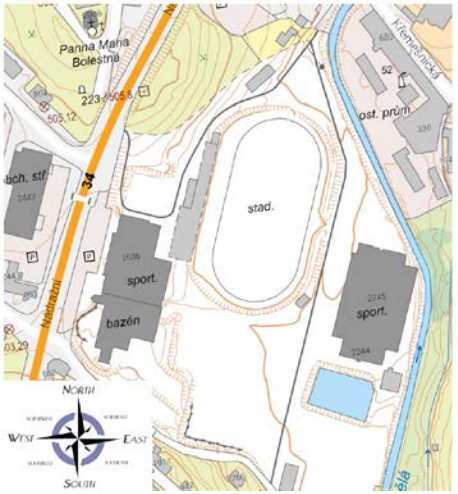
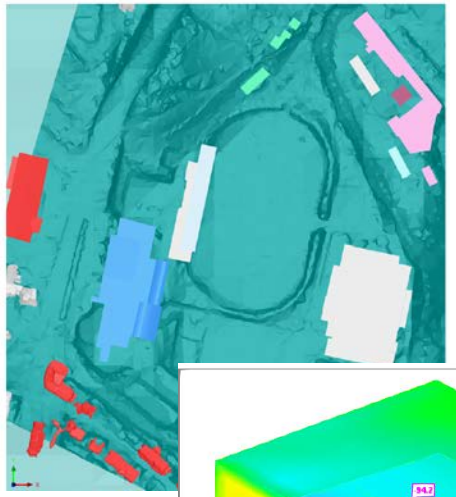
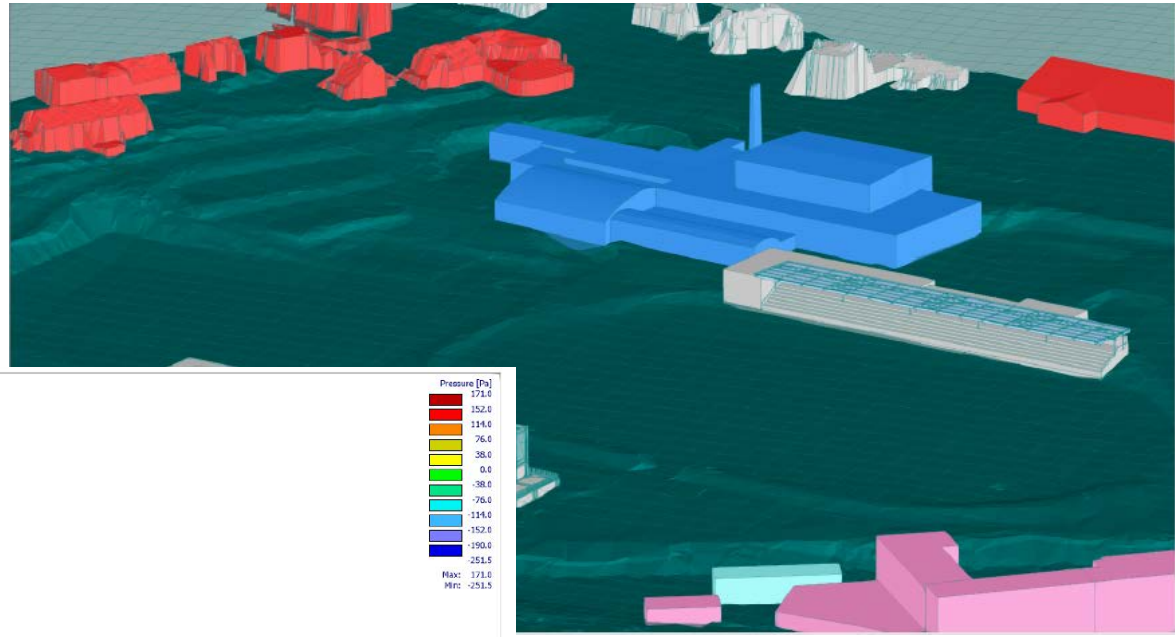
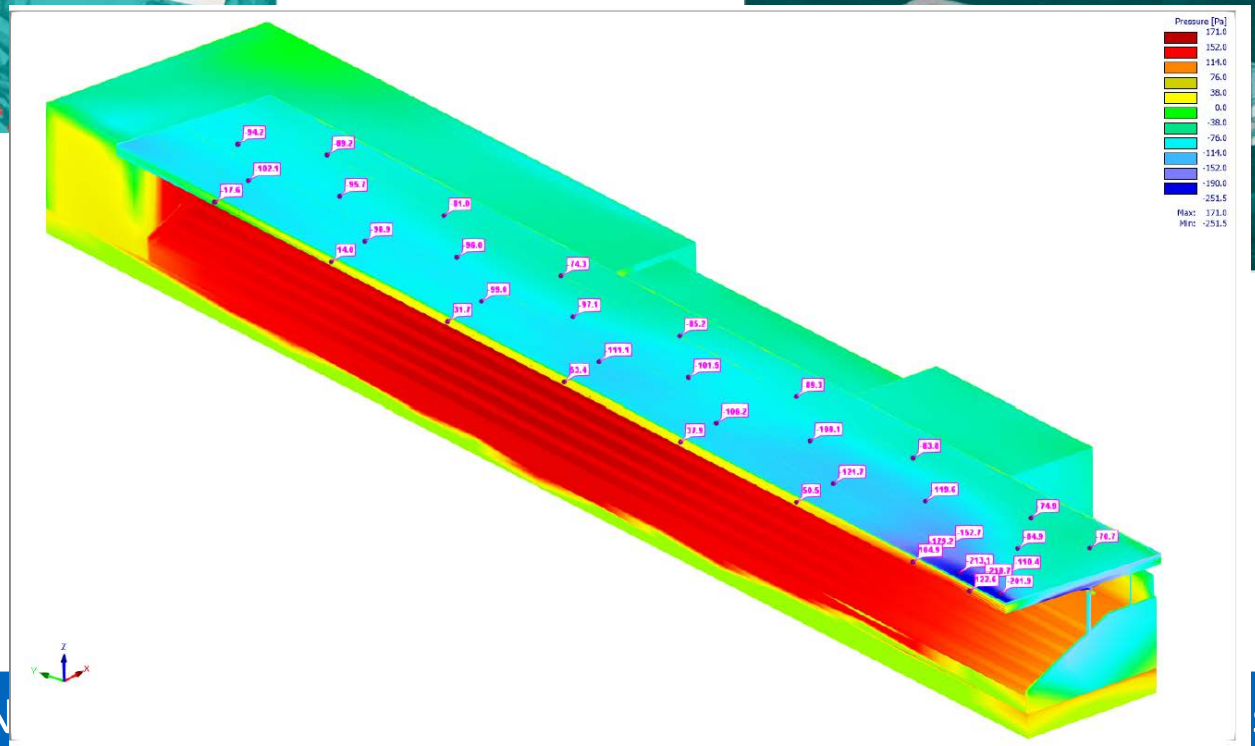
Hidden safety – shape and orientation of structure

- virtual wind tunnel (RWIND)









$\sim 0{,}5 W_{EN} \rightarrow \sim 0{,}35 W_{EN}$
open against weakest East direction

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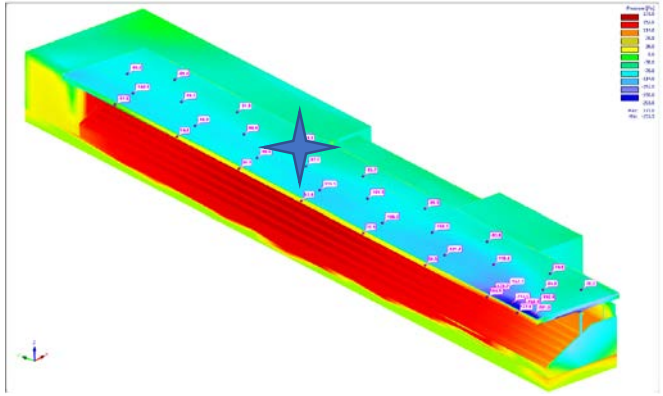
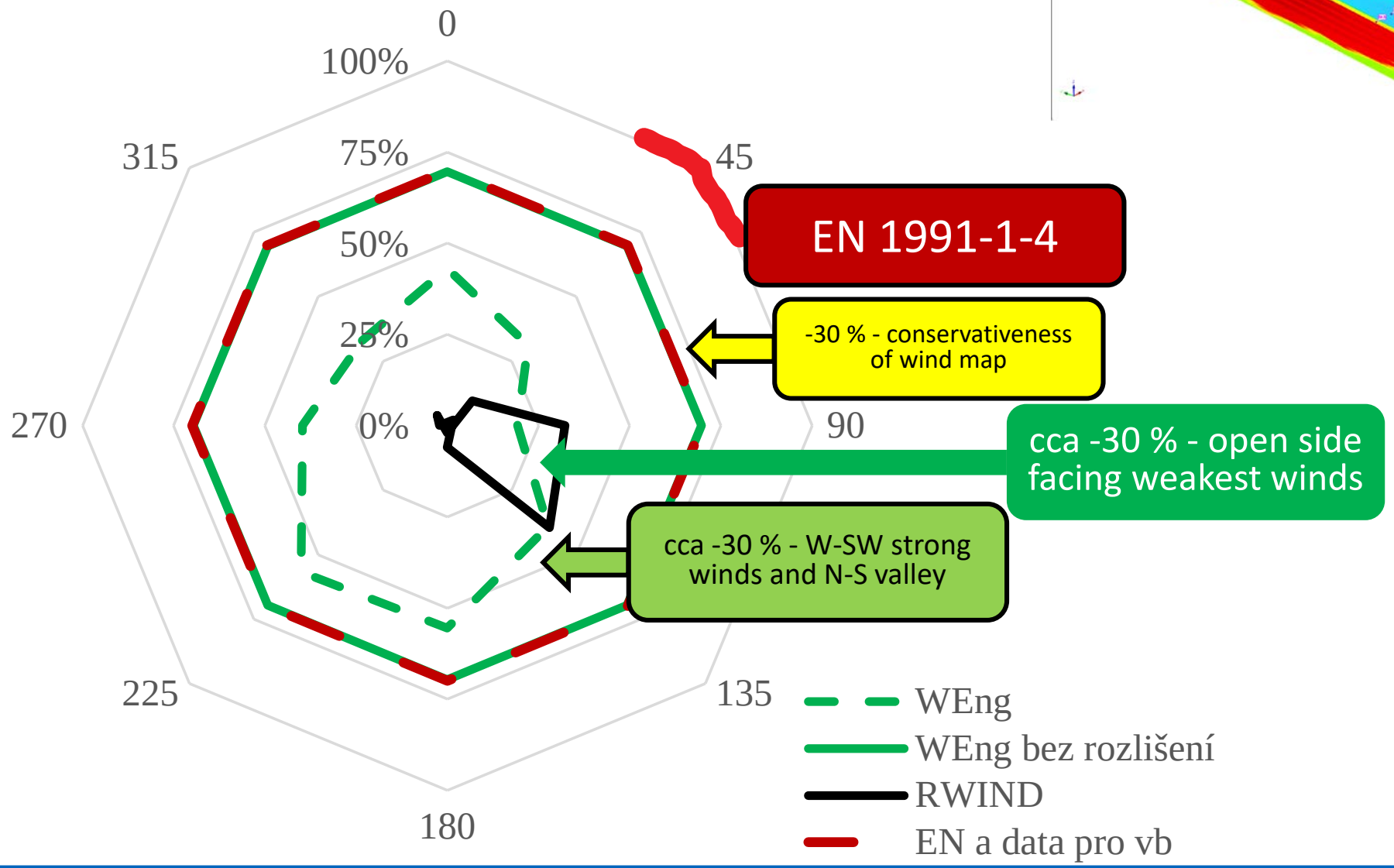
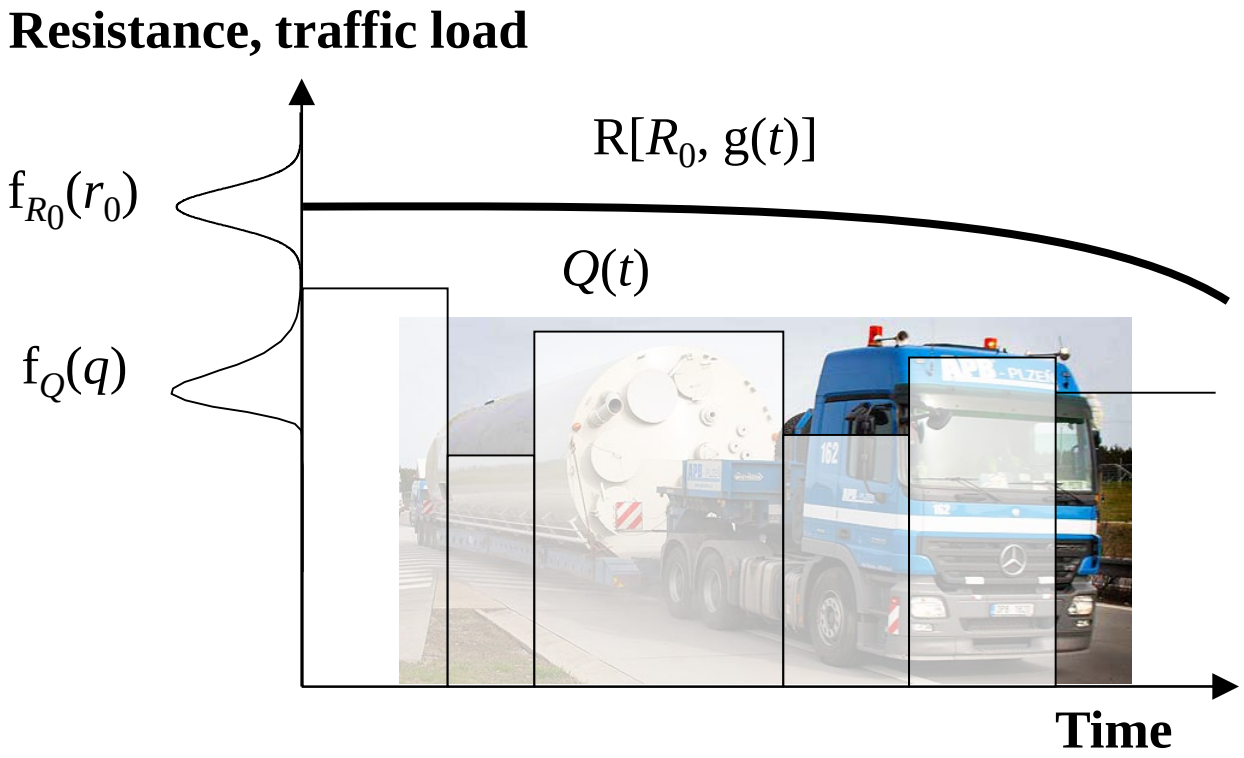
Hidden safety – summary





DISCUSSION - non-stationary cases

- Turkstra and FBC models – upper bound x
  - maximum load effect and minimum resistance may be overly conservative
- Renewal processes – efficient analysis using the Laplace transform
  - Rackwitz
  - ‘slowly’ degrading resistance



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Remarks for further discussions (conclusions?)

- Calibrations based on Turkstra, FBC and renewal processes – ***each approach has pros and cons***
  - comparable load effects?
  - implementation in softwares?
- Interaction of TV loads may present ***significant challenges*** in reliability modelling
  - lack of data
  - difficult to generalise
- ***Modelling of individual loads***
  - talk to your meteorologist!
  - structure- and site-specific investigations may pay back!

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Thank you for your attention!