Probabilistic Atmospheric characterization :

relevant Shear and Turbulence Intensity statistics

towards effective specification for
power curves, loads, ...

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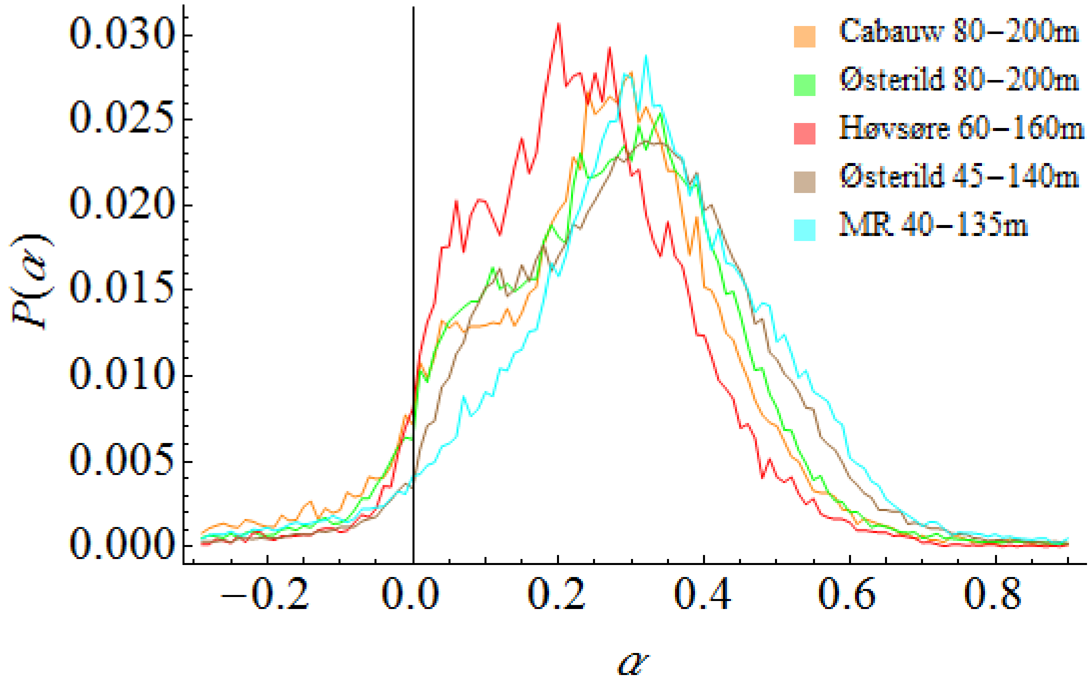
DTU Wind Energy
Department of Wind Energy
(formerly Risø)

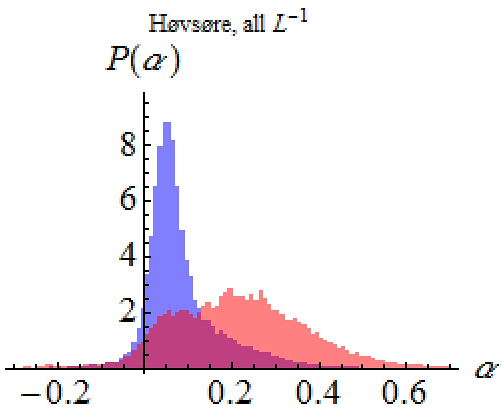
Shear Exponent α : distribution, at different sites

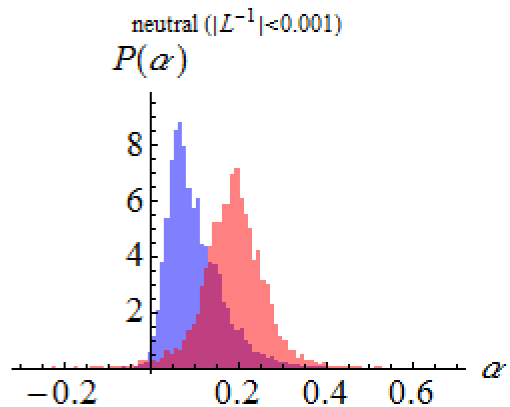


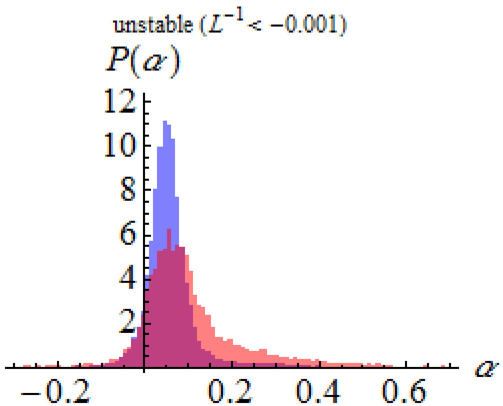
α depends on

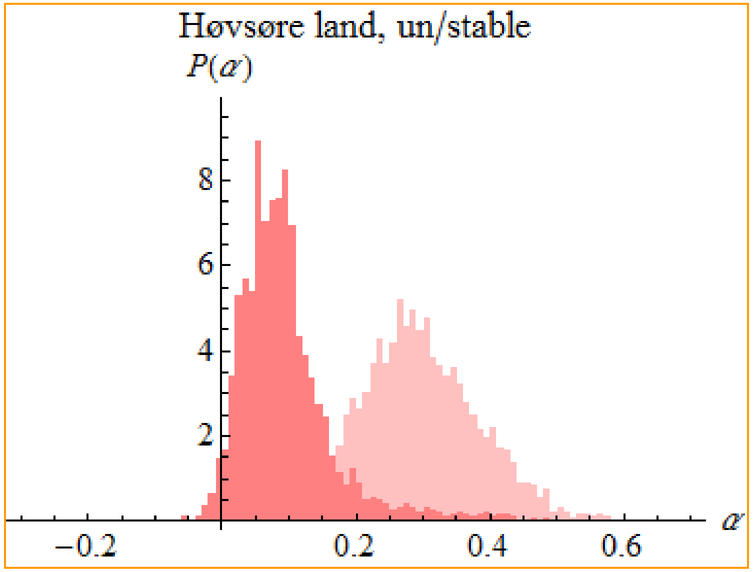
- $z/z_{0\text{eff}}$
- U
- …

Stability and shear…



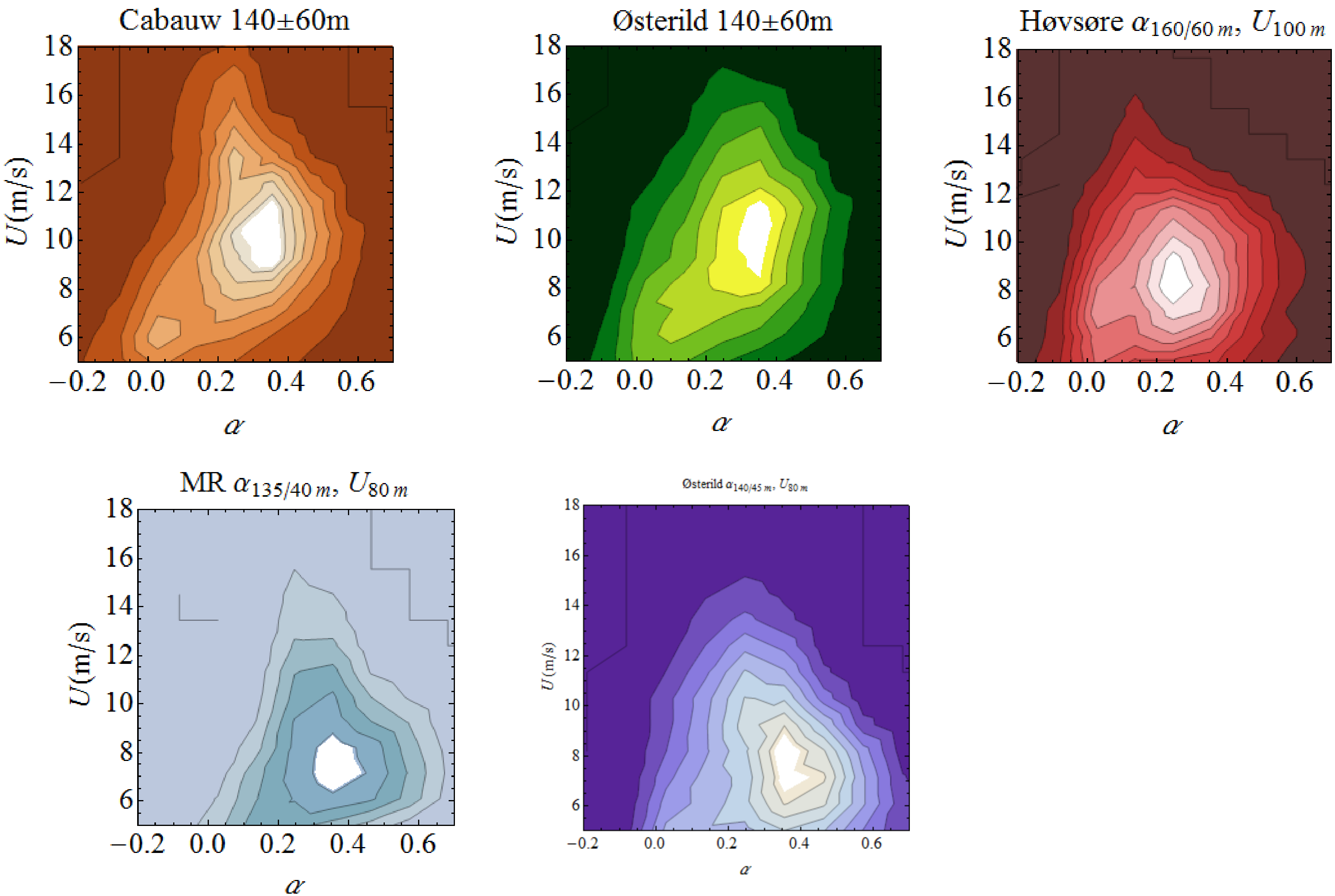






Contrast to ASL un/stable behavior…have theory for ASL…

$P(\alpha, U)$

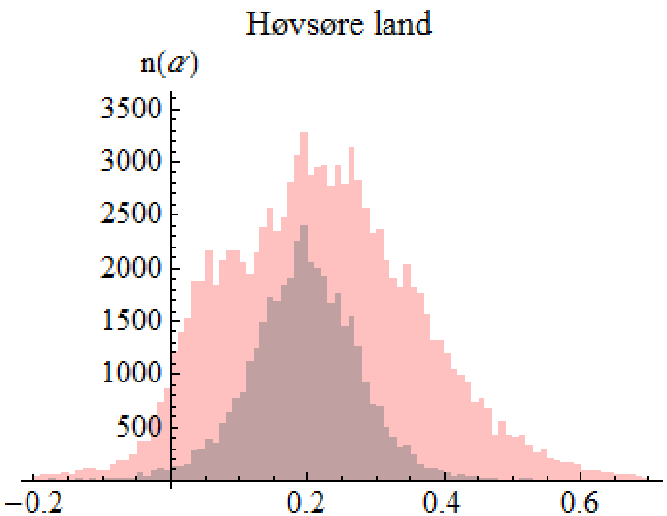


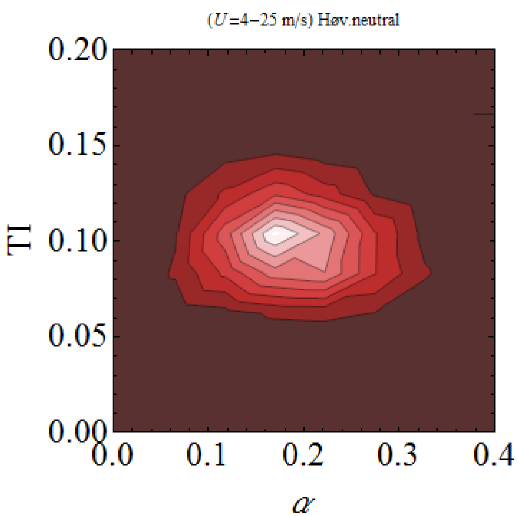
Cabauw 140±60m
Østerild 140±60m
Høvsøre $\alpha_{160/60\,m}$, $U_{100\,m}$
MR $\alpha_{135/40\,m}$, $U_{80\,m}$
Østerild $\alpha_{140/45\,m}$, $U_{80\,m}$
U(m/s)
18
16
14
12
10
8
6
−0.2
0.0
0.2
0.4
0.6
α

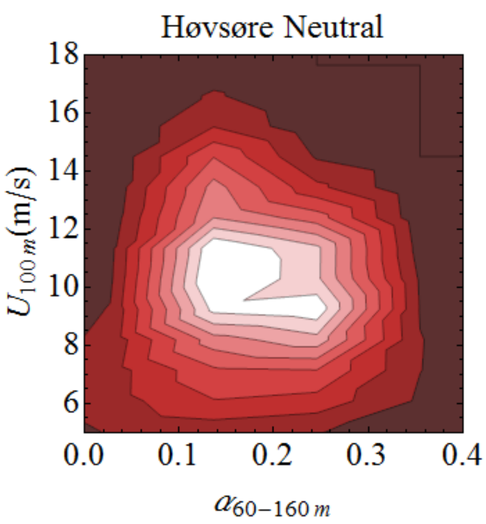
Effective roughness: via shear, ***above ASL***

- Peak of distribution: idea of effective roughness
  - since above ASL, surface roughness does not apply
    - Stability, terrain/inhomogeneity & transport effects

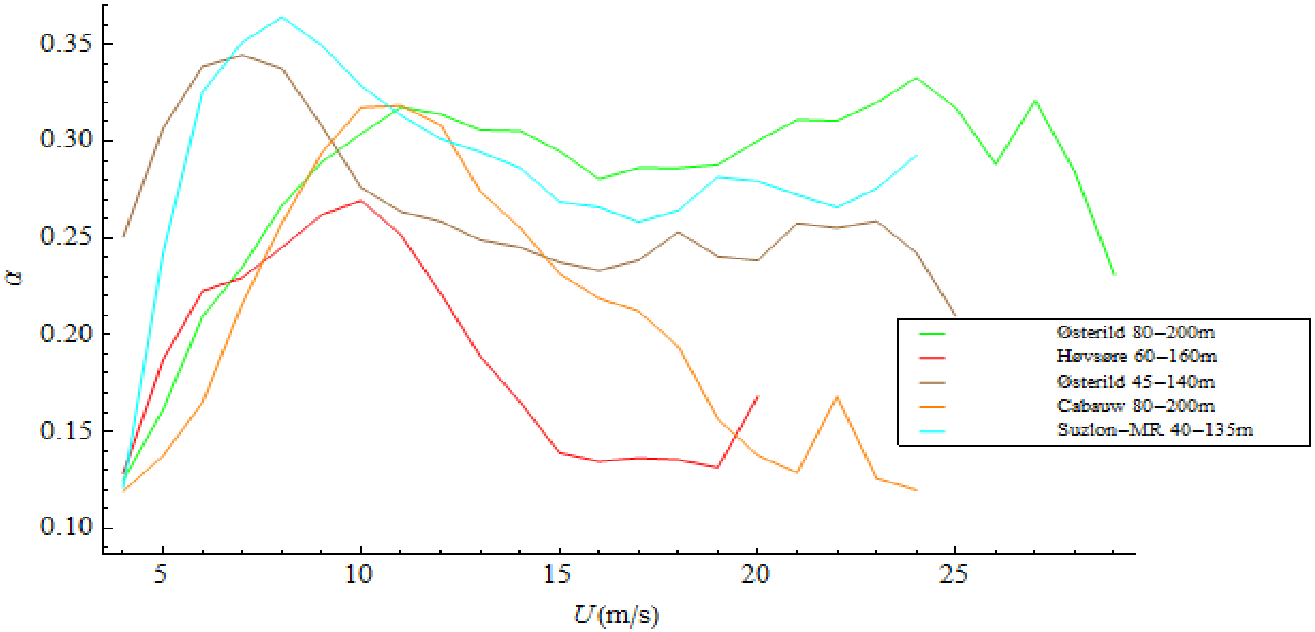
via <u>$P(\alpha)$ over all U</u>; <u>P(TI) over all U</u>; <u>P(U) over all TI</u>







Mean Shear Exponent $<\alpha|U>$, with site :

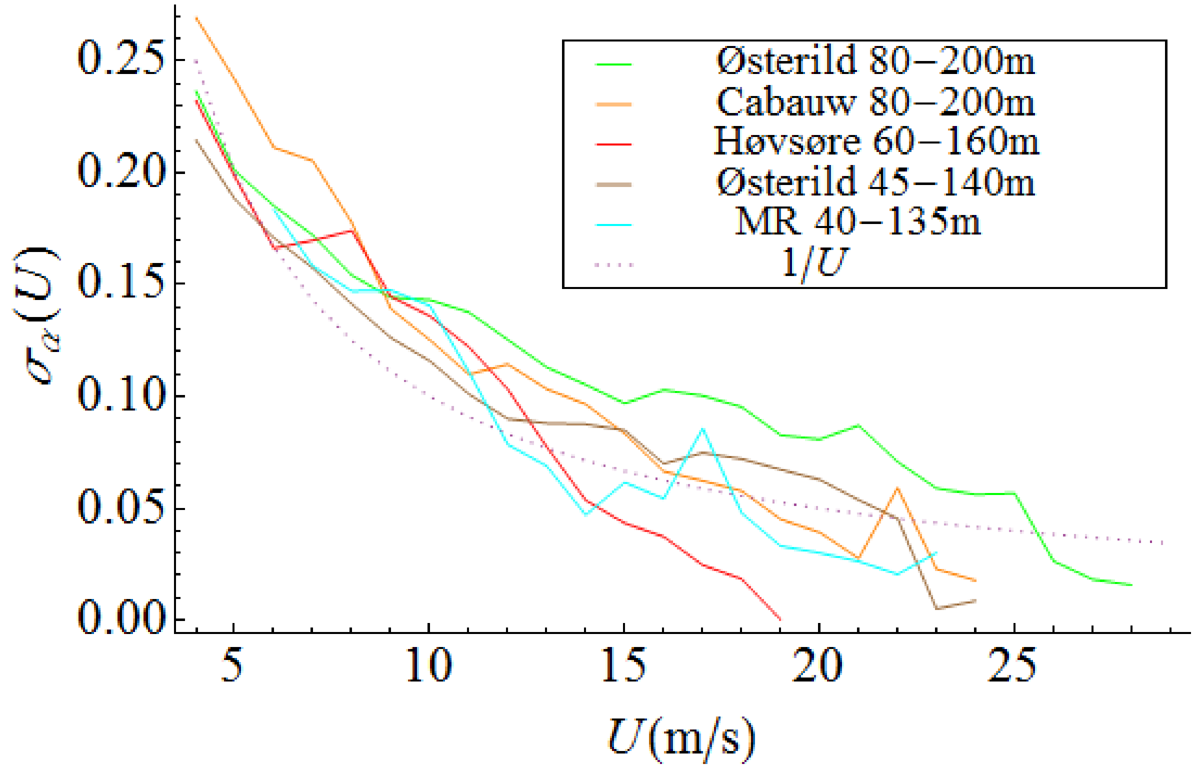


- increase with *U* from cut-in;
- peak at moderate *U,* then constant section*;*
  - filter out low TI (bottom half):

    → **Reach peak α then ~constant with *U*** *(not shown)*

  - lower $(z/z_{0,\mathrm{eff}})$ → larger peak α,

Variability in shear : $\sigma_\alpha \mid U$



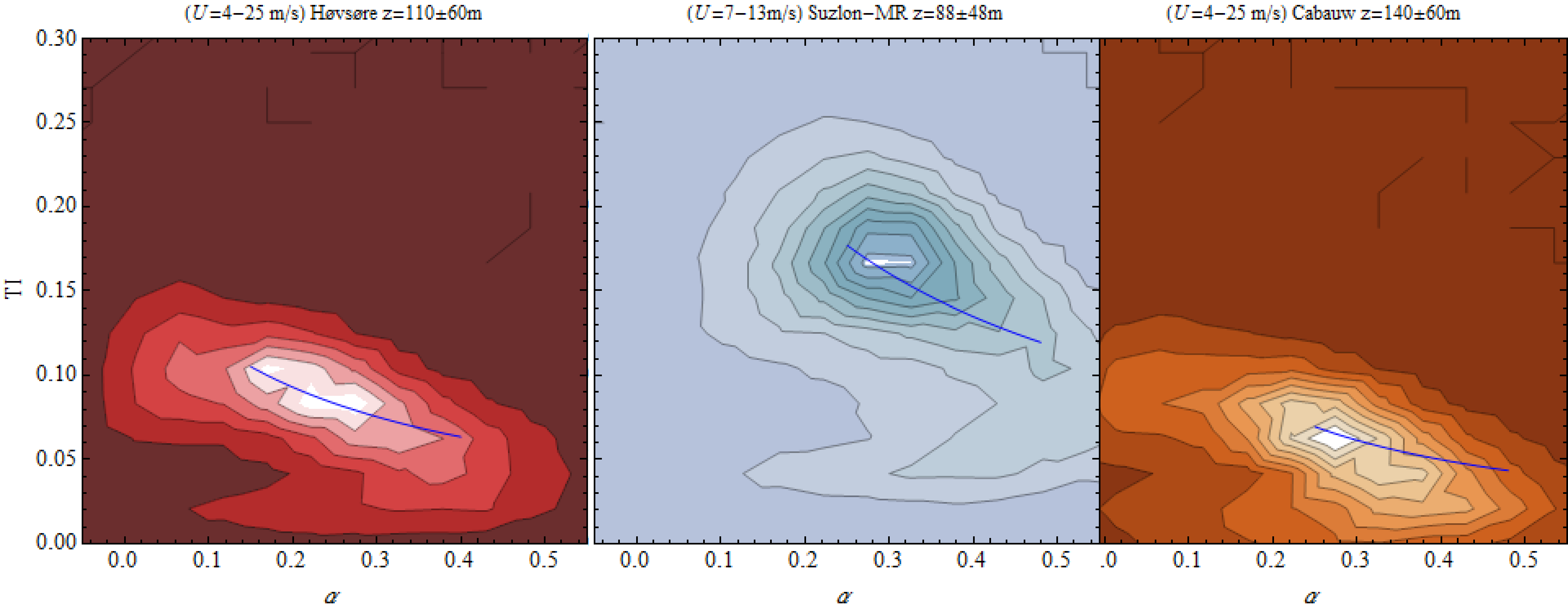
systematic behavior:

$$\sigma_\alpha(U) \sim 1/U$$

(+minor z/z0eff dependence)

TI(shear)

Due to stability, transport...<u>above ASL</u>



Form for mean TI(*alpha*) [or α(TI)]
based on stability-modified profile/TKE:

$$I = \frac{I_0}{1 + c_\alpha(\alpha - \alpha_0)}$$

‘simple’ application to power curves:

- Shear variability ($\sigma_\alpha \mid U$)

  already have modified Weibull

  → affects equivalent H.H. distribution

  (equivalent hub-height mean speed)

- TI-shear relation
  - use to modify equivalent wind speed

$\alpha \leftrightarrow$ *TI* assumption/use

normal stress-budget is not always this simple

- not just stability which influences TI (at low speeds)
- TI ‘flux’ possible (even when neutral, and z <~ 0.2h)
  - also for more complex terrain/higher roughness

- Asymptotic limit: when dissipation, shear production scale(U) similarly

  -Then ok assumption (better at high *U* over flat surface)

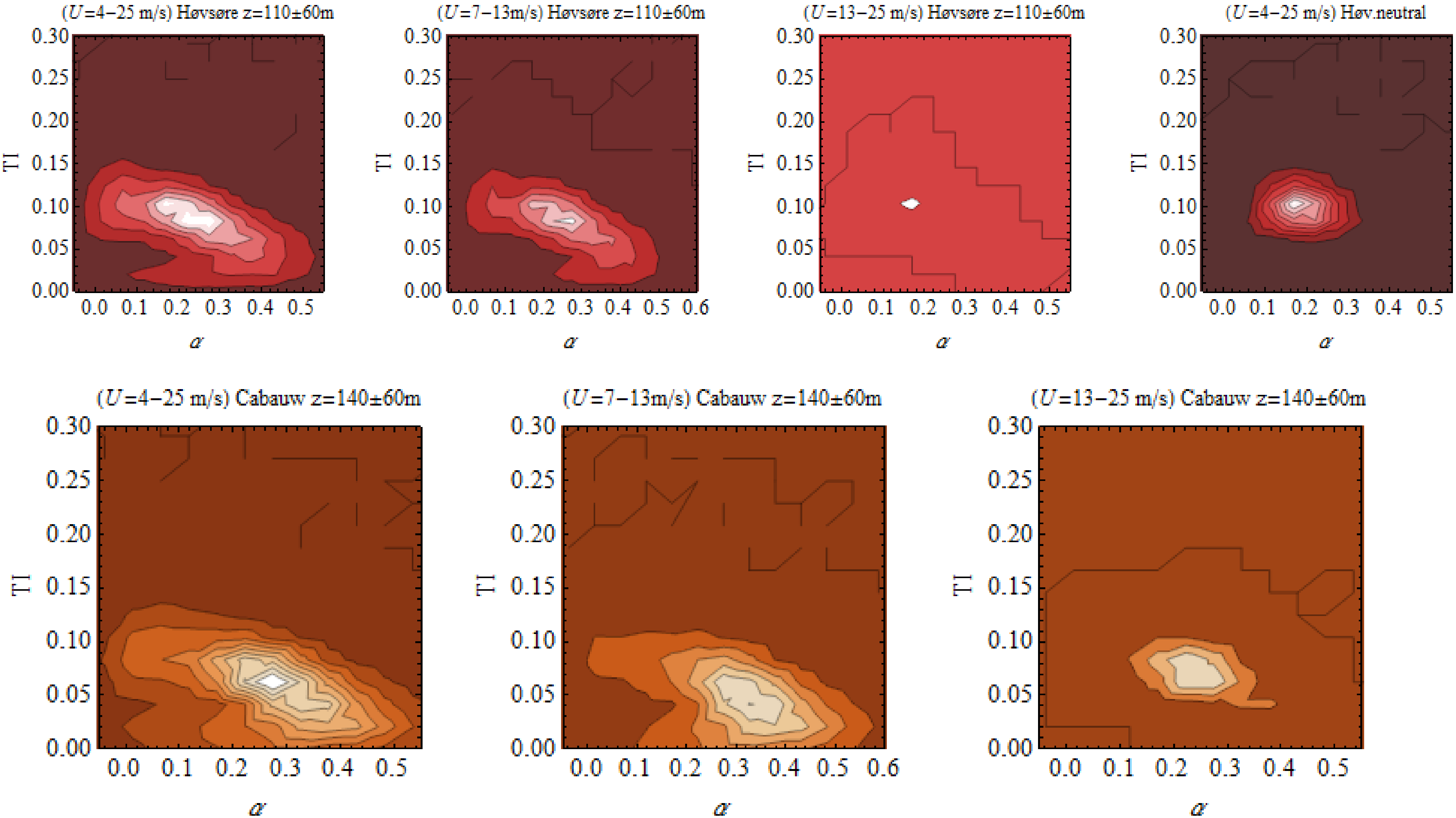
  - recall 10-minute TI contains some random noise

    (avg. of second moment!)

Extras follow...

P(Shear|TI)

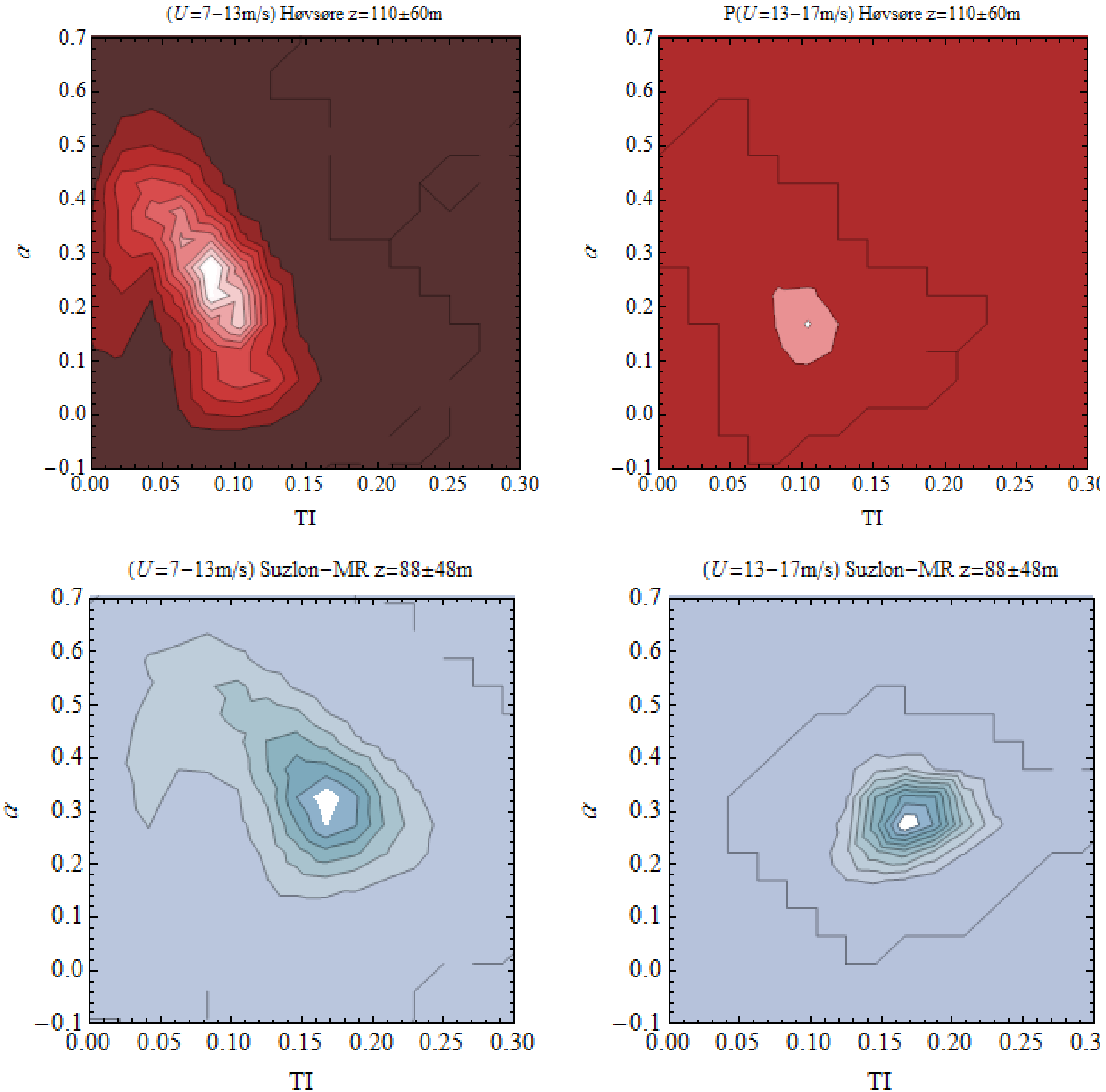
All stabilities (neutral: no trend)



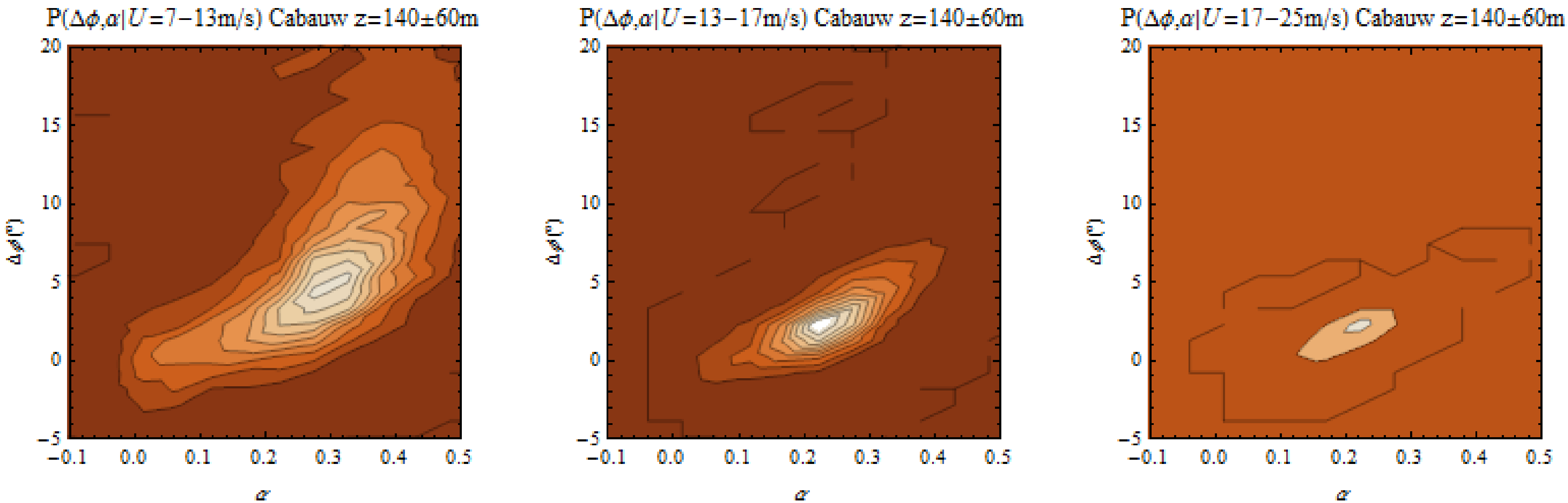
P(Shear|TI)

All stabilities

(neutral: no trend)

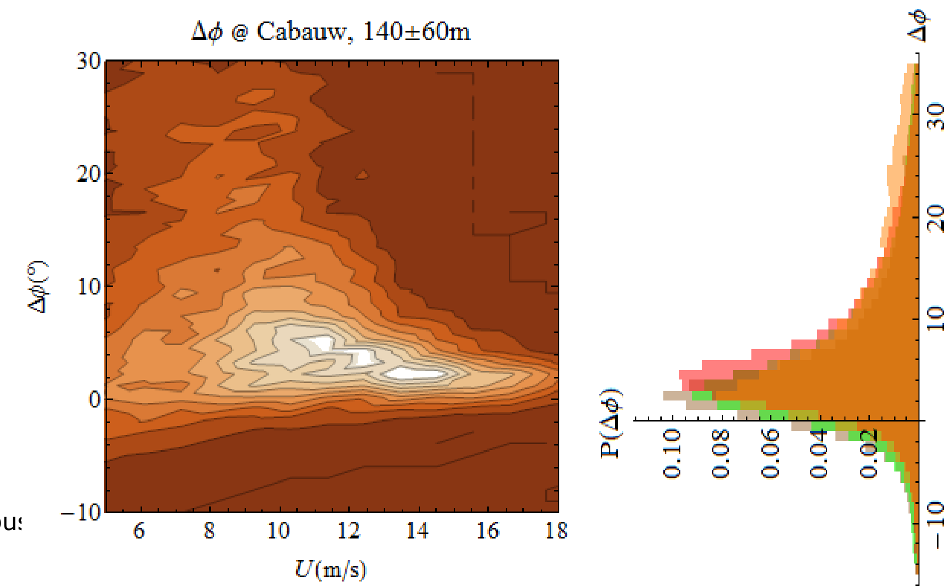


Distribution of Veer with Mean wind speed and Shear

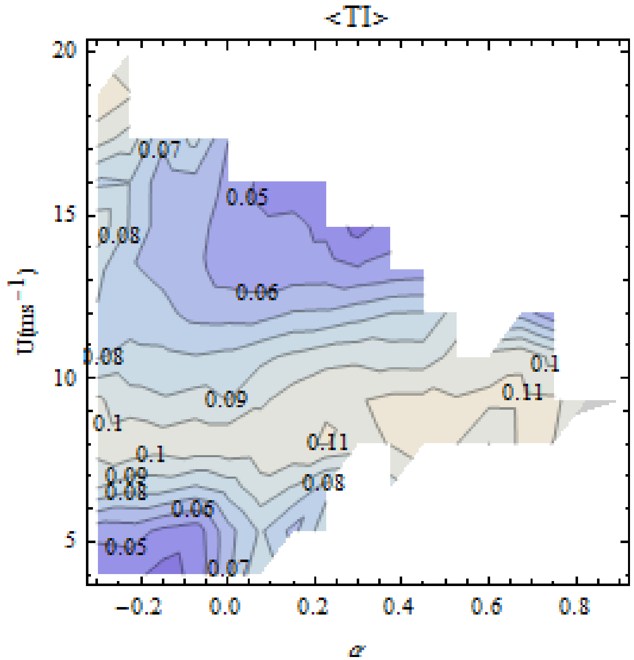


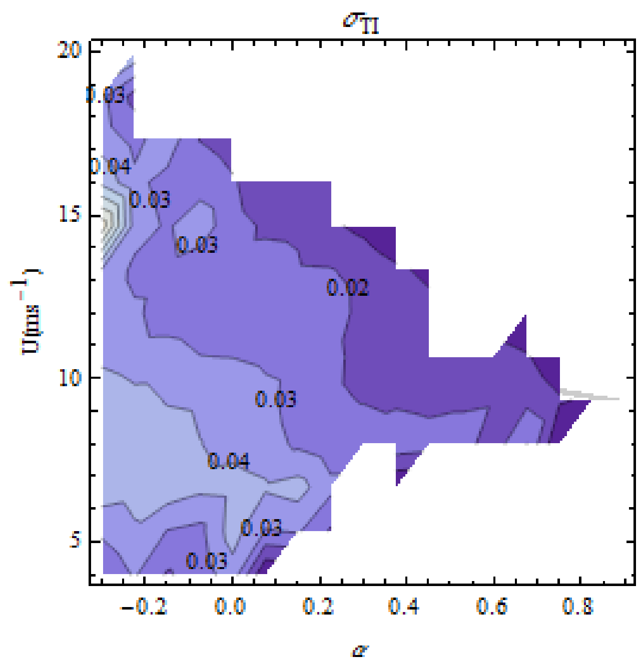
Shear-veer correlation is simpler at higher mean wind speeds and z/z_0.

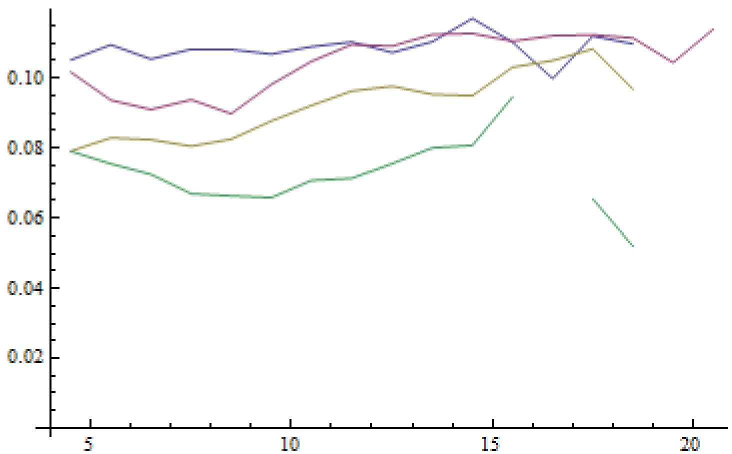
Correlation of $\sigma_{\Delta\phi}$ with U
(non-Ekman contributions…)

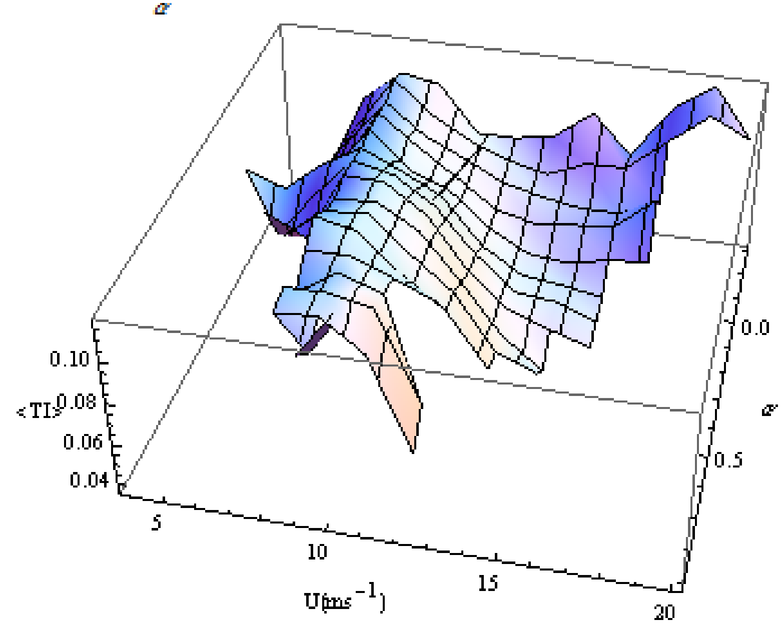


Shear-TI trend (Høvsøre, land, all stabilities)





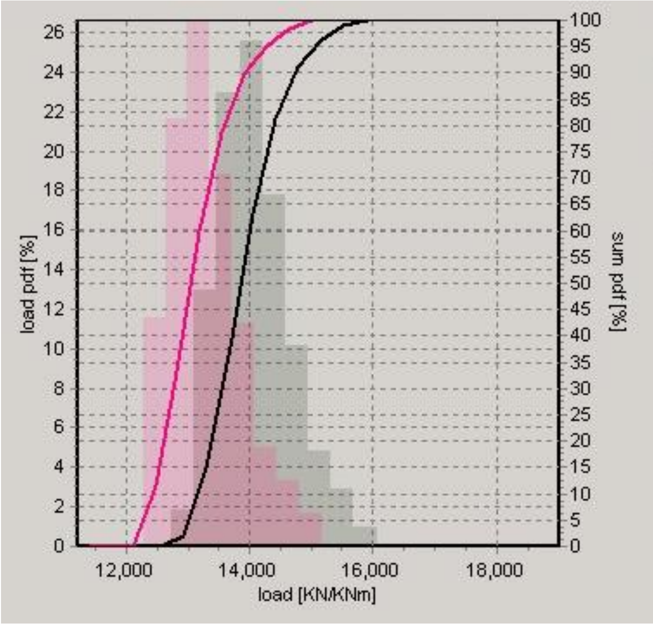


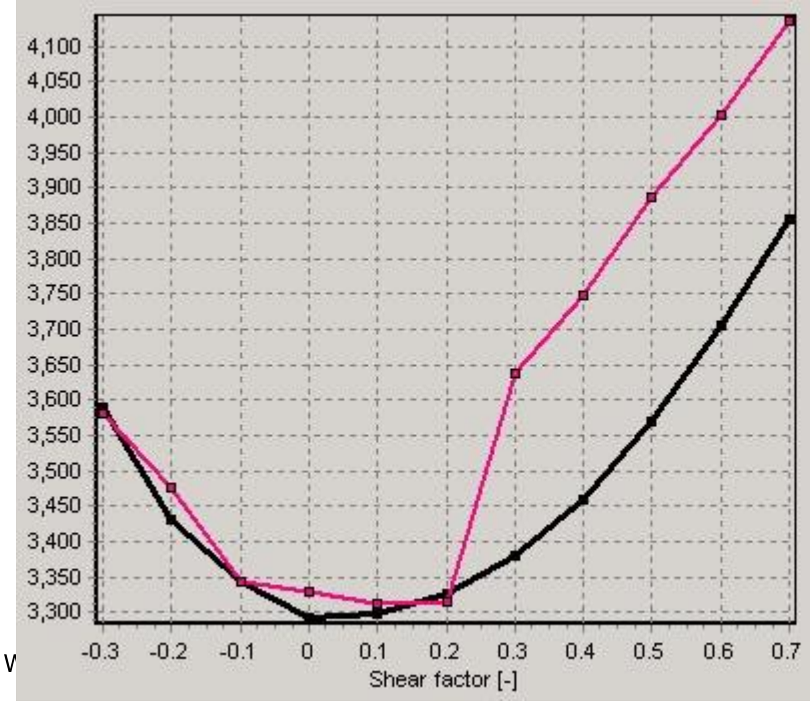


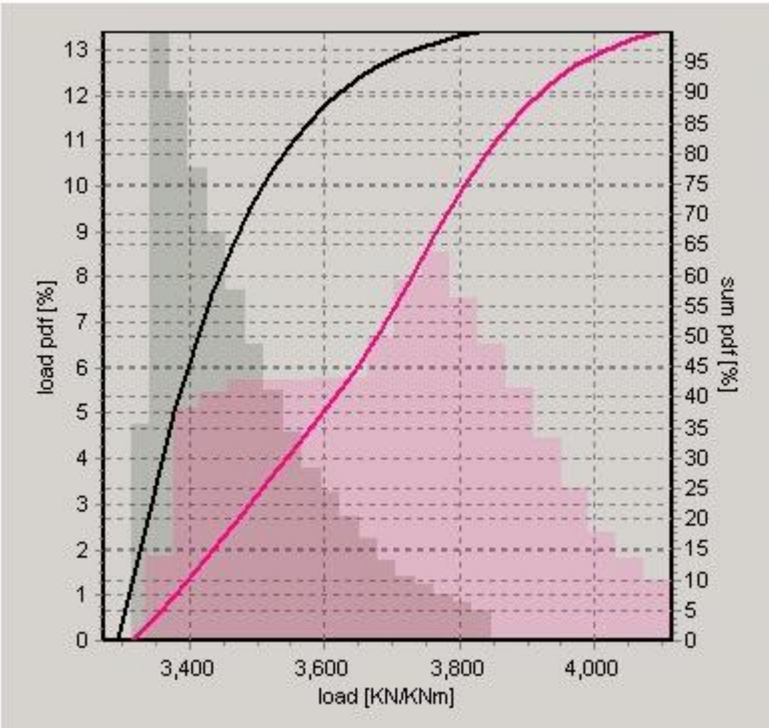
Shear exp. into loads...

Flapwise Blade root 1Hz equiv. moments (Mf)

25m/s,
5m/s





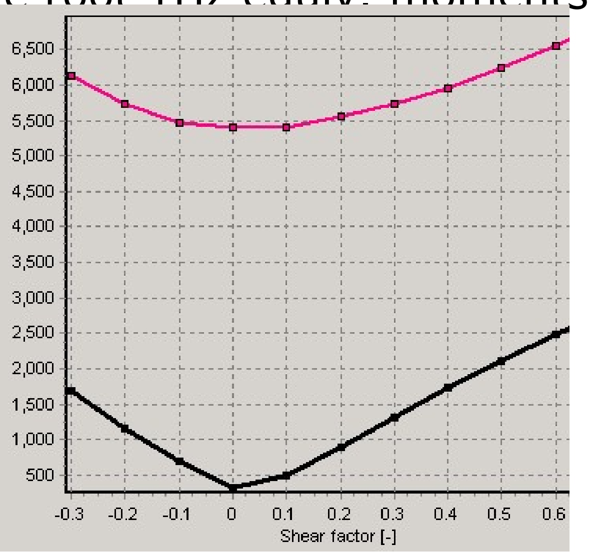


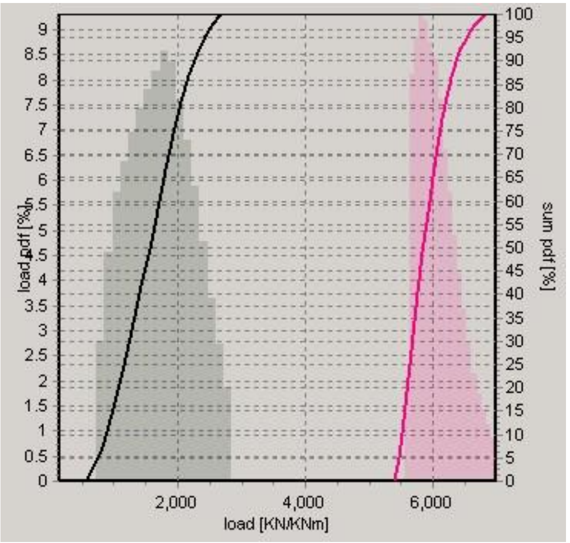
Shear exp. into loads...

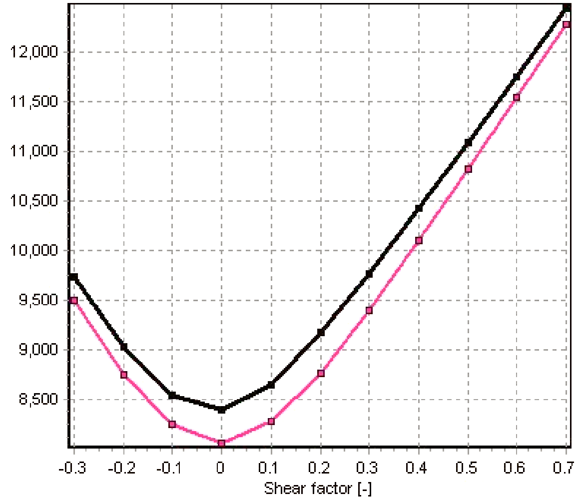
Flapwise Blade root 1Hz equiv. moments (Mf)

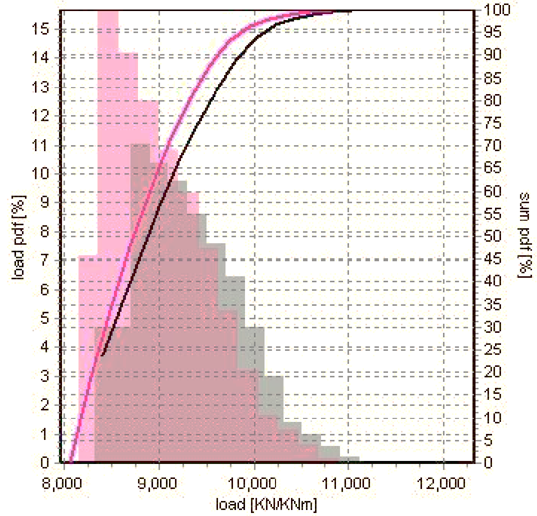
startup

15m/s,









Shear exp. into loads...

Tower bottom 1Hz equiv. moments

15m/s,

Recommendations

- Depends on the turbulence class (per eff.roughness); shear exponent α used in normal turbulence load cases must be updated:
  –
- For operational load cases near rated wind speed, over large rotors >100m, a veer of 5-10° should be used (not over forest)