Modelling of non-neutral wind profiles - current recommendations vs. coastal wind climate measurements

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Introduction

- Wind velocity at the hub height is a parameter of paramount importance for wind engineering.
- Wind velocity is very often extrapolated from other heights (measured or modeled) - an „old" question: what is the vertical wind profile?
- Logarithmic and power laws are valid only in neutral conditions.
- For non-neutral conditions – Monin Obukhov similarity theory (MOST) is a recommended practice [1,2].

Problem/Objective

- **How do MOST based vertical wind profile models perform?**
- **The test** – knowing the $v_{z=10m}$, humidity, pressure and temperature gradient extrapolate the velocity to $v_{z=100m}$ and compare it with measured velocity.
- **The place** – mid-Norway coast, the Frøya island.

Models tested

Stability corrected logarythmic model:

$$u(z)=\frac{u_*}{\kappa}\left(ln\frac{z}{z_0}-\Psi(\varsigma)\right)$$

$z/L \geq 0$: $\Psi(\varsigma)=-4.8(z/L)$

$z/L < 0$: $\begin{cases}\Psi(\varsigma)=2\ln(1+x)+\ln(1+x^2)-2arctan(x)\\ x=[1-19.3(z/L)]^{0.25}\end{cases}$

Panofsky&Dutton model:

$$\alpha(\bar{z}/L)=\frac{\Phi(\bar{z}/L)}{ln(\bar{z}/z_0)-\Psi(\bar{z}/L)}$$

$\bar{z}/L \approx 0$: $\Phi(\bar{z}/L)=1; \Psi(\bar{z}/L)=0$

$\bar{z}/L > 0$: $\Phi(\bar{z}/L)=1+4.7(\bar{z}/L);\ \Psi(\bar{z}/L)=-4.7(\bar{z}/L)$

$\bar{z}/L < 0$: $\begin{cases}\Phi(\bar{z}/L)=[1-15(\bar{z}/L)]^{-0.25}\\ \Psi(\bar{z}/L)=-ln\left[\frac{(\zeta_0^2+1)(\zeta_0+1)^2}{(\zeta^2+1)(\zeta+1)^2}\right]-2[arctan(\zeta)-arctan(\zeta_0)]\\ \zeta=[1-15(\bar{z}/L)]^{0.25};\quad \zeta_0=[1-15(z_0/L)]^{0.25}\end{cases}$

Peña boundary layer height corrected model:

$$u(z)=\frac{u_*}{\kappa}\left[ln\left(\frac{z}{z_0}\right)-\Psi(\varsigma)\left(1-\frac{z}{2z_{sl}}\right)\right] \quad z_{sl}=0.1\cdot 0.25\frac{u_*}{f_c} \quad u_*=\sqrt{\frac{\kappa^2}{\left(\ln\frac{z}{z_0}\right)^2}}\cdot u_{z=10m}$$

Smedman&Högström model:

$$\alpha=c_0+c_1log(z_0)+c_2[log(z_0)]^2$$

Stability class	c_0	c_1	c_2
Very Unstable/Unstable	0.18	0.13	0.03
Neutral	0.3	0.17	
Weakly Stable	0.52	0.2	
Stable	0.8	0.25	
Very Stable	1.03	0.31	

Site, equipment & data description

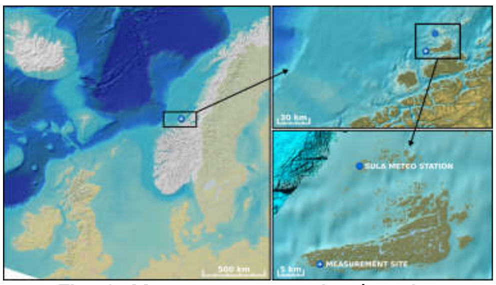

Fig. 1. Measurement station location

Fig. 2. Met mast

- 100 m high Met-mast.
- Velocity (Gill Wind Observer IID) & temperature measurements at: 10, 16, 25, 40, 70 and 100 m.
- Pressure & humidity from nearby Sula meteostation.
- Data acquisition time: Nov 2009-Dec 2012.
- Approx. 160000 of 10 min samples for each height.

Atmospheric stability

For atmospheric stability calculations we used the bulk Richardson number as a basis for Obukhov length calculation:

$$Ri=\frac{g}{\overline{\theta_v}}\frac{\Delta\overline{\theta_v}z_m}{(\Delta u)^2}ln\left(\frac{z_1}{z_2}\right) \qquad L=\begin{cases}\frac{z_m}{Ri}, & Ri<0\\ \frac{z_m}{Ri}(1-5Ri) & 0\leq Ri\leq 0\end{cases}$$

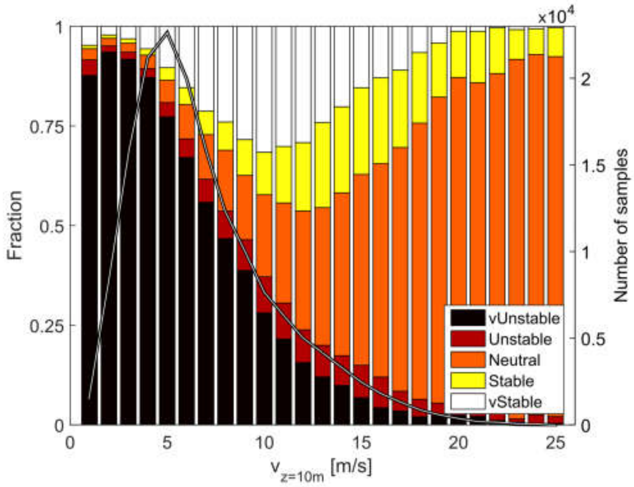

Fig. 3. Atmospheric stability distribution.

Results

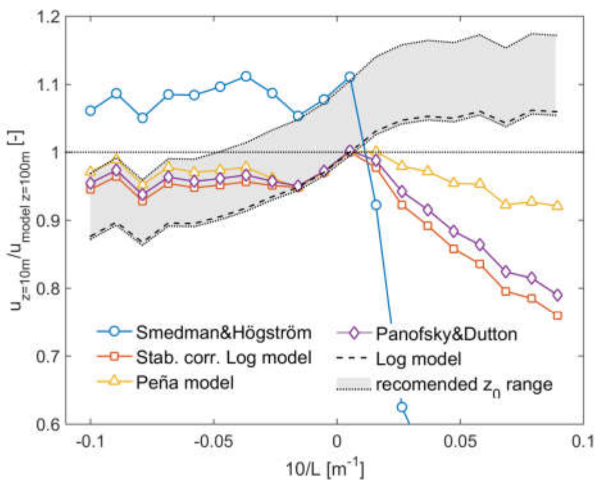

Fig. 4. Wind speed ratio between the measured and predicted wind velocity at z_2=100m against atmospheric stability.

Conclusions

- 5 % underestimation of predicted wind velocity is observed during unstable conditions.
- The deviation grows dramatically up to 20 % (!) in stable atmosphere.
- Given the frequency/number of non-neutral observations that can result in serious error in wind prediction and finally in wind resources estimation.
- Although the problem of is not new, a lot of space for improvement is visible and desired.

References

[1] DNV, G. (2014). DNV-RP-C205: Environmental conditions and environmental loads. DNV GL, Oslo, Norway.
[2] Fisher, et al., (1998). COST-710–final report: harmonisation of the pre-processing of meteorological data for atmospheric dispersion models.