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Atmospheric stability: general classification and simulation in meteodyn WT

C. Albrecht[1], D. Delaunay[2], Dr. A. Grötzner[3], M. Kohlert[1], L. Pauscher[4]
[1]AL-PRO GmbH, [2]Meteodyn, [3]CUBE Engineering GmbH, [4]Fraunhofer IWES

Abstract

Recently, the impact of atmospheric stratification on the shape of the wind profile attracts more and more attention in wind energy applications. Specifically, for the extrapolation of wind speed measurements to modern large hub heights a reliable modeling of the vertical velocity gradients is essential. Moreover, modeling wind conditions in complex terrain requires knowledge about atmospheric stability as well since it influences the circulation over and around hills and mountains. Further, experience has shown that sometimes atmospheric conditions cannot be approximated by neutral or slightly stable conditions. Determination of in-situ-stability and its usage in CFD modeling could improve the situation.

Objectives

1) Establishing a suitable way to determine in situ stability from reanalyses
2) Analysis of typical stability situations and distributions for sites all over Europe
3) Developing a method for considering these distributions in wind resource assessment

Determination of atmospheric stability

- Use of two high quality measurements at high met towers:
  - Cabauw/Netherlands (200m, flat)
  - Rödeser Berg/Germany (200m, complex)
- Use of two mesoscale reanalyses:
  - ConWX (3km resolution)
  - Vortex (3km resolution)

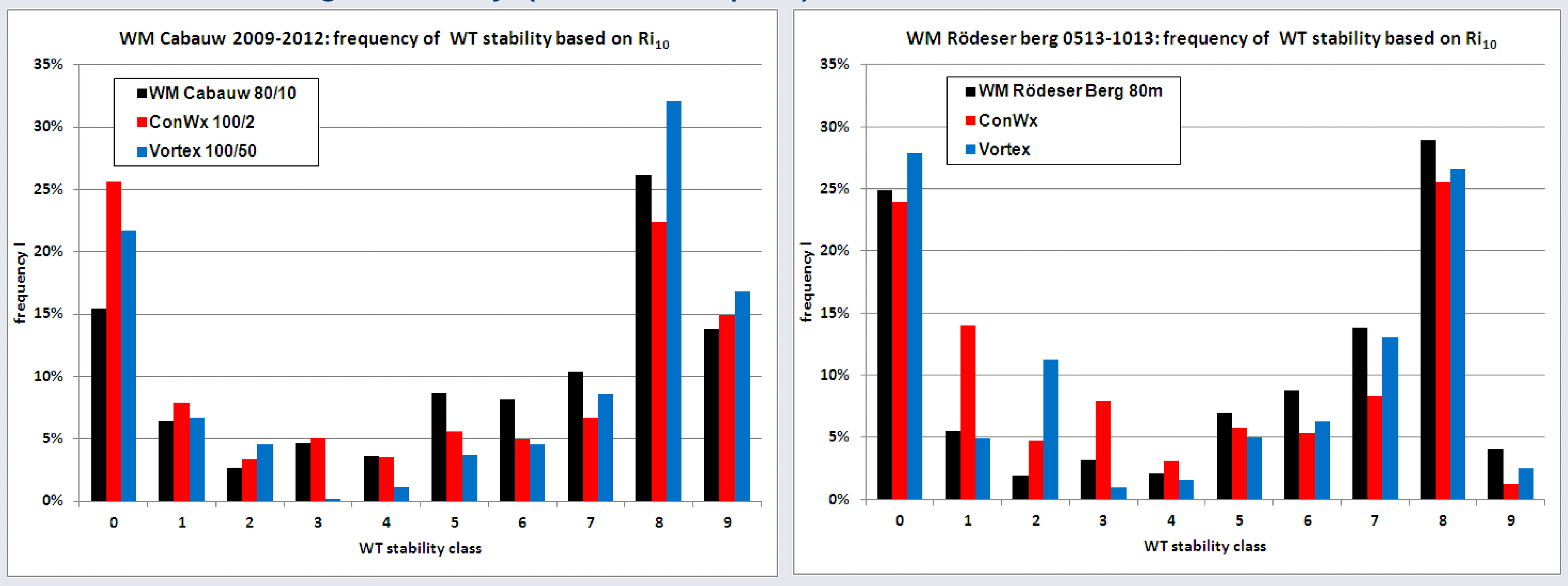


Figure 1: Frequency of occurrence of stability at both sites

- **ConWX and Vortex data fit reasonably well to the measured frequency of occurrence distributions of meteodyn WT stability classes.**

- The energy contained in the wind is composed by the strength of the wind and its frequency of occurrence → Energy weighted frequency distributions should be used to investigate the relative importance of the stability classes:

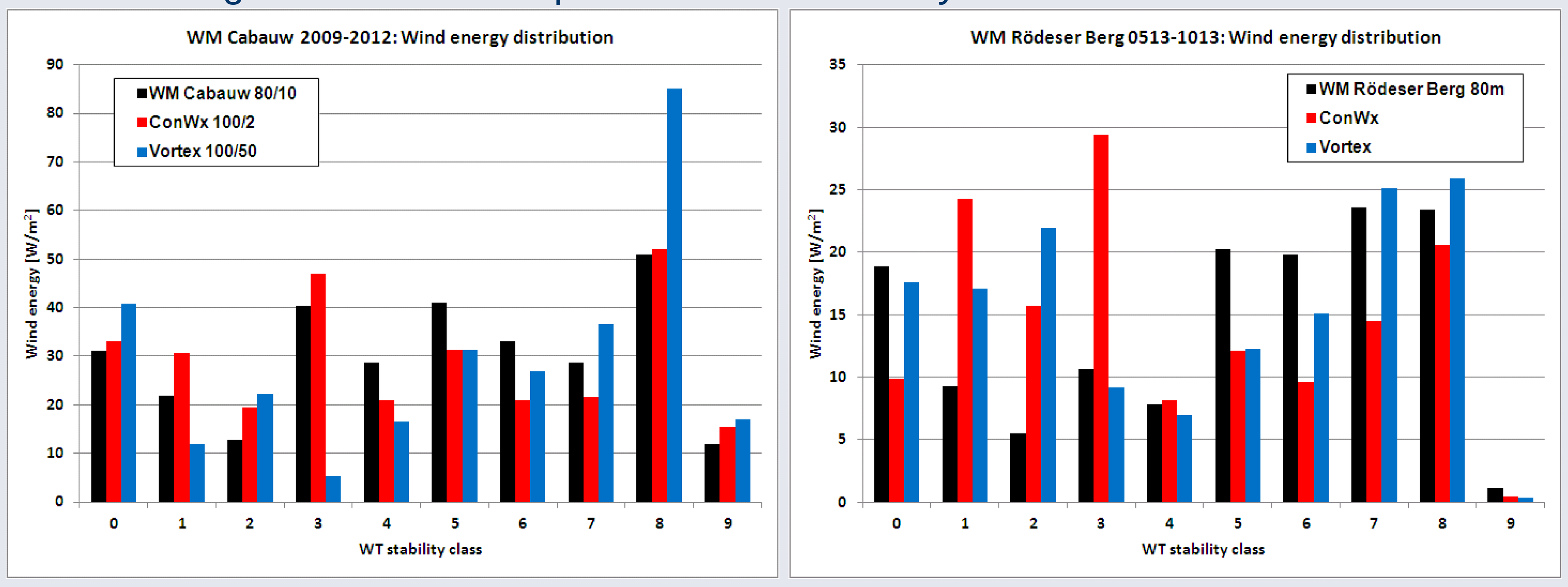
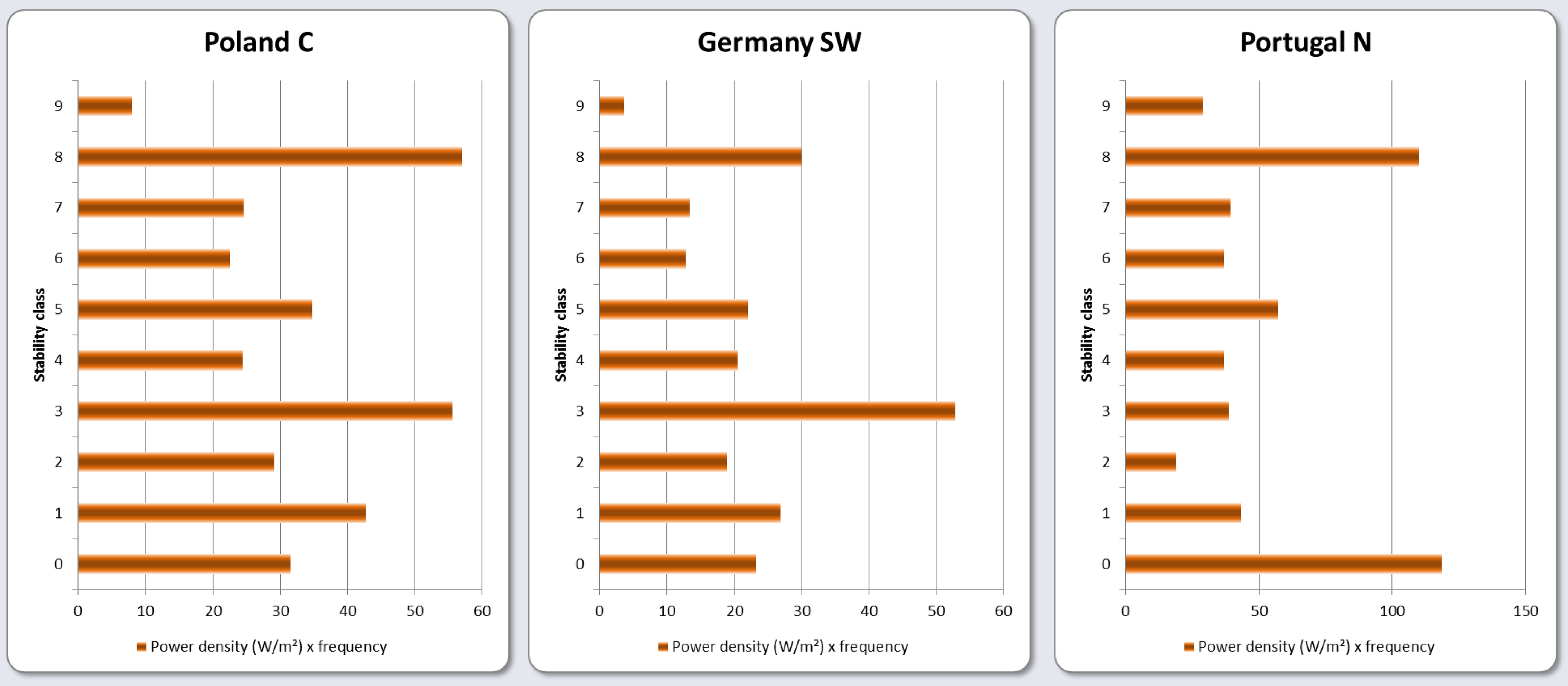


Figure 2: Energy distribution depending on stability at both sites

- **The observed energy distribution is reasonably well captured by the ConWX reanalyses**

Spatial structure of stability distributions over Europe



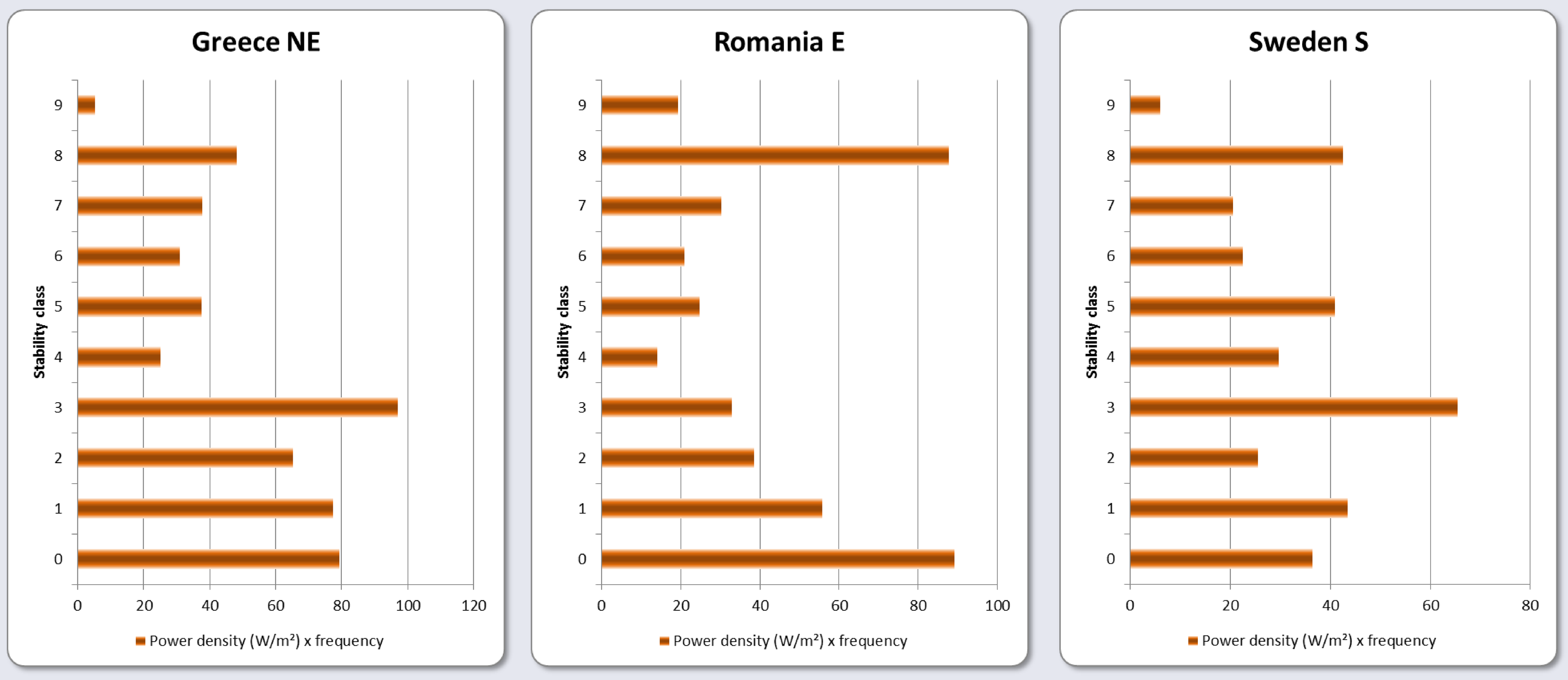


Figure 3: Energy distribution depending on stability at several sites in Europe

- Atmospheric stability is dependent on the climatic conditions for different locations
- In many regions, especially in central and east Europe, strong stable atmospheric conditions are dominating → such flow effects have to be taken into account

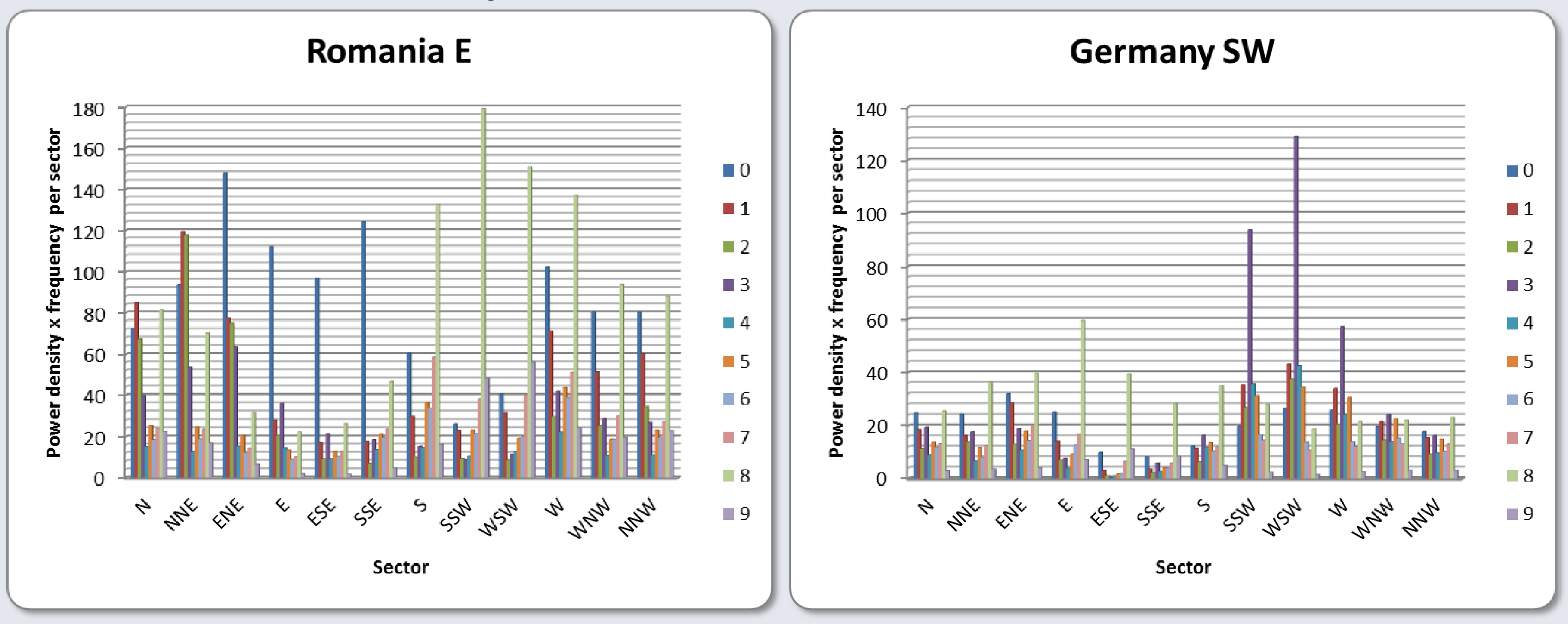


Figure 4: Sectorwise stability distribution of East Romania (South Eastern Europe) and South West Germany (Western Europe)

- **In many cases the directional sectors are dominated by one stability class →** not necessary to model all stabilities in each sector, but to concentrate on one stability class in each case.

A new approach for CFD modelling in stable situations

- Development of a new multi-layer model for the turbulent viscosity in case of strong stable situations and large heights (considering MOST layer, Local z-less model, free layer according to ref 1, 2,3)
- Implementation inside the Meteodyn WT software
- Calibration on 3 years westerly winds at Cabauw (between 40 m and 200 m height), with data sorted according to the Stability Index (z_1= 10 m and z_2= 80 m, given by:

$$SI = \frac{g}{\theta_1} \frac{(\theta(z_2)-\theta(z_1))/(z_2-z_1)}{[(V(z_2)-V(z_1))/(z_2-z_1)]^2}$$

	S03	S04	S05	S06	S07	S08	S09	S10	S11	S12	S13	S14
SI range	0.00 - 0.01	0.01-0.05	0.05-0.10	0.10-0.15	0.15-0.20	0.20-0.25	0.25-0.32	0.32-0.40	0.40-0.50	0.50-0.70	0.70-1.00	> 1.00
frequency	7.3%	9.4%	14.4%	11.2%	9.0%	6.9%	6.7%	4.5%	3.4%	3.1%	1.6%	1.9%
power contribution	9.1%	24.1%	21.4%	9.6%	6.0%	4.0%	3.5%	2.1%	1.4%	1.0%	0.4%	0.2%
(V80+V140)/2 (m/s)	8.1	11.3	9.5	8.0	7.4	7.1	6.8	6.5	6.2	5.8	5.2	4.3

Table 1: SI classes and characteristics at Cabauw (wind direction: 255-285 deg)

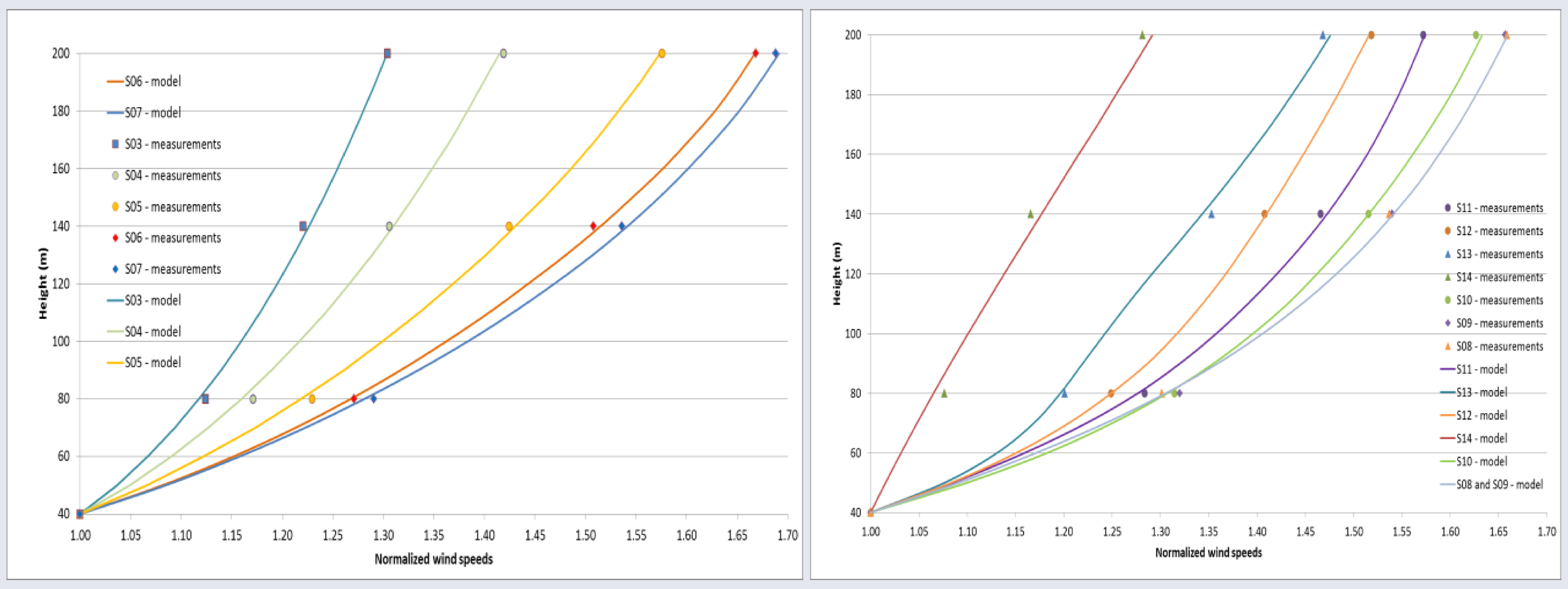


Figure 5: Meteodyn WT simulations of the Cabauw wind profile using the new turbulent multi-layer viscosity model

- **Applying a *k-L* multi-layer model for large heights or strong stability is a promising way to reproduce observed behavior of the Stable Boundary Layer**, especially when the height of the SBL becomes inferior to the wind turbine hub heights!

References

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3. Zilitinkevich, S. S., Eleperin, T., Kleeorin, N., Rogachevskii, I., L'vov, V., Esau, I., Kouznetsov, R. (2010) "Turbulence closure for stably stratified flows: local and non-local formulations", 8th European Conf. on Applied Climatology, EMS-2010, Zürich, Switzerland, 13-17 September 2010.

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