Measuring Wind Velocities at Varying Heights Above Ground

Johannes Juul[1] (SEAS)

Originally published as Tech. Paper No. 39 in: Technical Papers Presented to the Wind Power Working Party, Committee for Productivity and Applied Research (P.R.A). Working Party No. 2 (Wind Power), Organisation for European Economic Co-Operation (1954) [OEEC54][2].

As known[3], the wind velocity increases in proportion to height above ground or sea level, the wind being retarded by friction ensuing between the air and the solid components.

If the ground surface is uneven, tree-covered or built on, resistance to the wind mill will, obviously, be stronger than if the ground is level and without impediments to the wind. Inland conditions, therefore, will to a very great extent depend upon localities, while wind velocities over the sea surface will evidently be more stable according to height above the surface of the sea.

When constructing wind power stations, it is most important to take these circumstances into consideration.

On a 55 m height steel mast, which serves for carrying a 50 kV line across the Masned Sound[4], wind measurings[5] at heights of 5, 15, 35 and 55 m were carried out, simultaneously, at different wind velocities and different wind directions during the summer of 1952. The anemometers were mounted on fixtures on the mast in such a way as to make them work without being influenced by (eddies in the air from) the mast, when the wind was blowing from SW and NE. Thus it was possible to measured velocities of winds blowing directly from W (from "Smålandshavet", i.e. "the Ocean of Small Islands") and land winds from N and NE from Zealand.

The measurings were carried out by simultaneously reading the anemometers[6] 25 times running about half minute intervals[7], the average for each anemometer being computed thereafter.

Such averages exist from about 50 separate measurings.

In Figure 1 some of the most typical measurings are shown. The figure at the top of each line indicates the serial number of the measuring and on the map, Figure 3, the corresponding directions of the wind are marked by the identical figure.

From this it will be seen that the wind velocity – at winds not exceeding 10-12 m/s – is very nearly the same at 15, 35 and at 55 m height, when blowing from W, from the "Smålandshavet", as shown by curves 9 and 30, whereas a noticeable difference occurs at high winds about 15-18 m/s,

---

[1] Born in 1887, Juul was 66 years old in 1953. He started his wind power research and experiments in 1947, with financial and technical support from SEAS (Sydsjællands Elektricitets Aktieselskab), the electricity utility he had been working for since 1926 (later, his projects will be sponsored by public authorities, see [Nielsen1999]). On the list of delegates, in [OEEC54], his title is "Department Engineer, South East Zealand Electricity Co. Ltd., Haslev, Denmark". Note: the company still exists today, see https://www.seas-nve.dk/eng. The life and works of J. Juul, as well as the organisation of the are documented in [Thorndal1], [Thorndal2], and [Nielsen1999] (among others).

[2] The Wind Power Working Party was a west-European technical working group, under the patronage of the OEEC. Notable members of the group were chairman Daniel Dresden (NL), Edward Golding (UK), and Louis Serra (FR).

[3] On the history of wind energy engineering, see for instance Section 6.7 of [SOLARI], which points towards some of the earliest studies of wind profiles, carried out by Stevenson (1880) and Archibald (1885).

[4] See https://www.openstreetmap.org/#map=16/54.9981/11.8882 and Figure 3. Aerial pictures of the site, taken in 1954, are provided in Figure 4 and Figure 5. Figure 6 shows a picture of the power plant and its surroundings, including (possibly) the lattice tower on which the sensors were mounted.

[5] Juul uses the word "measurings" while we would write today "measurements".

[6] It is not clear what type of anemometer was used, maybe were they the ones designed, constructed and calibrated by Juul, and described in [Juul49].

[7] This makes a 12.5 minutes measurement period.

shown by curve 7. In one single instance, shown by curve 15, a smaller velocity was measured at 55 m height than at 15 m.

Land winds, contrarily, have velocities considerably increasing with increasing height above ground. This is shown by curves 32-42.

Wind effects increasing by the cube of the velocity, the working power of the wind will be strongly increasing in comparison to height, where land winds are concerned. This is shown by Figure 2, where the wind velocities measured are translated into wind effect.

Increase in relation to height is shown in percent on the abscissa.

The results of the measurings show, that at small height fairly good wind conditions are obtained along the coasts. Western winds being predominant in Denmark, it will, consequently, be the western coasts that offer the most favourable conditions for wind power stations.

Best conditions for wind power stations will be obtained on promontories of flat islands.

Such localities are to be found within SEAS distribution area on South Falstria, Knushoved, Enø, Dybsø, and Svinø. Here, winds from NW, W, SE and S will be sea winds and, the coastline having a flat hinterland easterly winds, too, will have fairly good effect at low height.

Northerly winds occur but rarely and are mostly light breezes. During the period in which measurings were carried out, namely from the beginning of June till December, winds above 5 m/s and due N occurred a couple of time only. Land winds of the same velocity as along the coastlines do, of course, occur, but over land areas it is necessary to go for a height of 50-100 m in order to find the same wind velocities as are met at 15-20 m height on the coasts.

On inland hillocks and eminences, wind conditions similar to those prevailing along the coasts will probably be found, although of more varying velocities.

References

[Juul49]	**Juul J.** Investigation of the Possibilities of Utilization of Wind Power. Trans/IB1025 in: Translations published by ERA of Wind Power Articles, 1930 to 1949. ERA Trans-3012, Energy Research Agency (1975). The original article, Undersøgelse af muligheder for vindkraftensudnyttelse, was published in Elektroteknikeren Vol. 45, pp. 607-635 (1949-10-22). Link: https://drive.google.com/file/d/1ORFsVR22J1sH-s1b0-k4-gUYFKQe_M6Q/view
[Nielsen99]	**Nielsen K. H.** Interpreting Wind Power vs. the Electric Power System: A Danish Case-Study. Centaurus 1999: Vol 41: pp. 161-177. Link: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1600-0498.1999.tb00279.x
[OEEC54]	**Organisation for European Economic Co-operation.** Committee for productivity and applied research. Working party no.1 (Wind Power), Technical Papers Presented to the Wind Power Working Party (London: H.M. Stationary Office, 1956). Link: https://drive.google.com/file/d/1mJJ1EzJaMyWrp_abQvBRVYmTp5Da3l4g/view
[SOLARI]	**Solari G.** Wind Science and Engineering. Origins, Developments, Fundamentals and Advancements. ISBN 978-3-030-18814-6. Link: https://link.springer.com/book/10.1007%2F978-3-030-18815-3
[Thorndahl1]	**Thorndahl J**. Johannes Juul og hans vindmøller. Link: https://drive.google.com/file/d/1HzB0NV7l4TqyAJwuWylNGCroiLkmxgM6/view
[Thorndahl2]	**Thorndahl J**. En dansk vindelektriker. Elektrikeren Link: https://drive.google.com/file/d/1N6C4Sc3mhpLyDclJlgZ9WO5TSrlPrgQ4/view

Figures

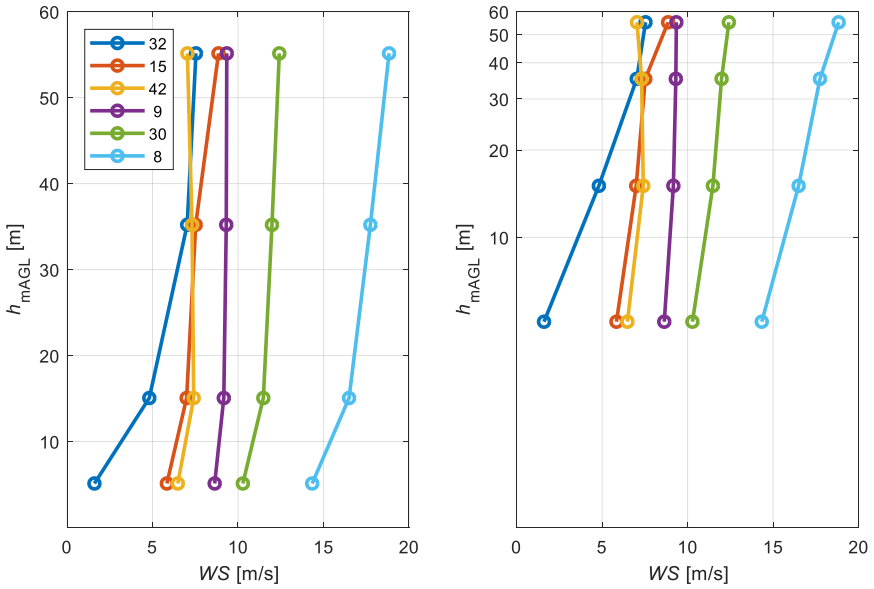

Figure 1: Left: Reproduced from Figure no. 6 of the original article in [OEEC54]. Right: same as on the left, but using a logarithmic y-axis (this plot was not present in the original article). The numbers in the legend correspond to the wind directions shows in Figure 3.

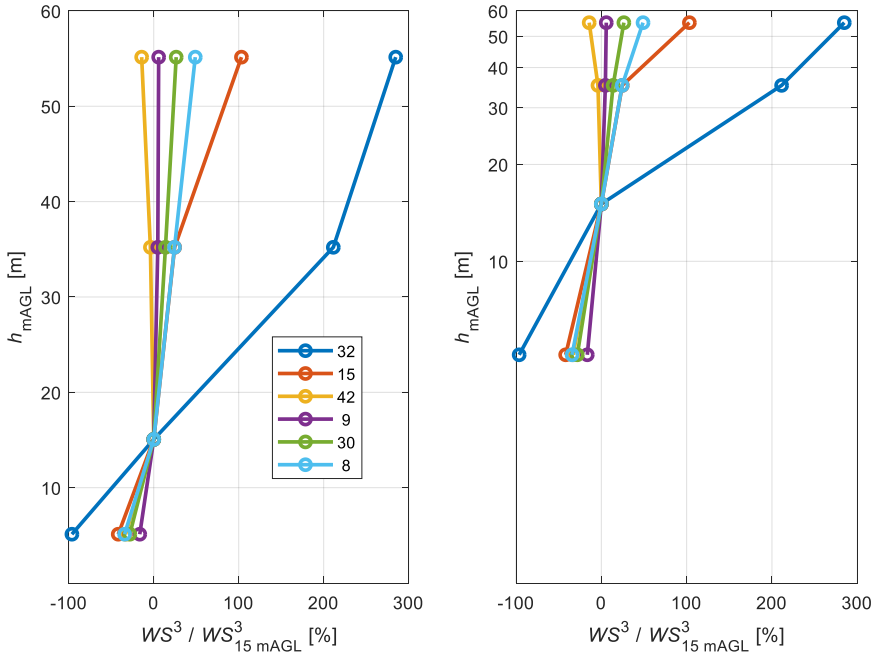

Figure 2: Left: Reproduced from Figure no. 6 of the original article in [OEEC54]. Right: same as on the left, but using a logarithmic y-axis (this plot was not present in the original article). The numbers in the legend correspond to the wind directions shows in Figure 3.

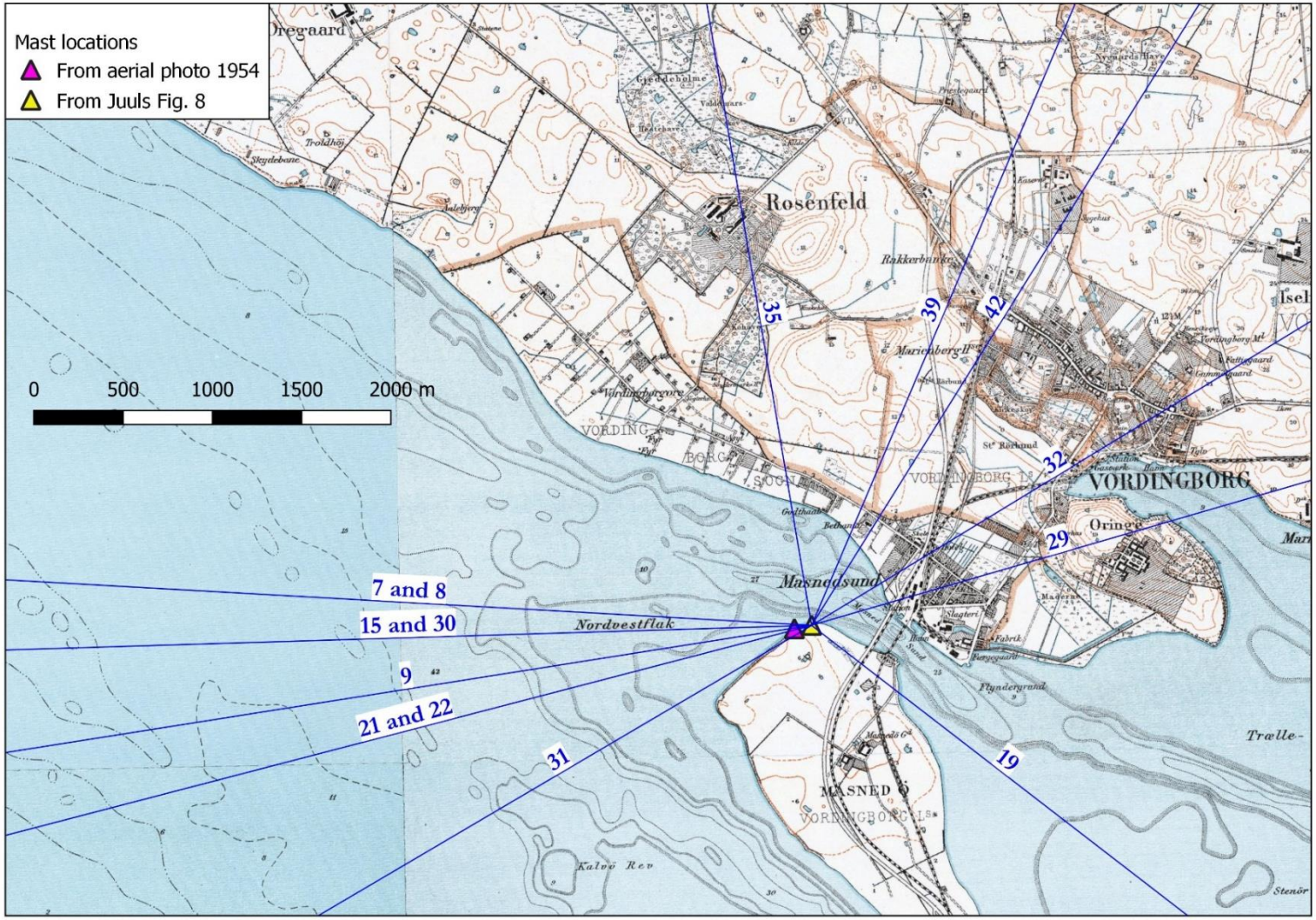

Figure 3: Reproduced, yet slightly adapted, from Figure 8 in the original article. The background map in this Figure (and also, very likely in the original article), is the "lave målebordsblade 1901-1971", here available from https://download.kortforsyningen.dk/content/dtklave-m%C3%A5lebordsblade.

Figure 4: Aerial picture from 1954 showing the Masned Sound, Vordinborg and the Masned island power station. Source: https://map.krak.dk,

Figure 5: Same as above, only zoomed onto the power plant. The power line lattice tower that was (likely) used for this experiment, is visible to the North-West of the plant. See also Figure 6. Source: https://map.krak.dk.

Figure 6: Photograph of the Masned Island power station, where the power line tower is visible. Source: https://arkiv.dk/vis/3576685.