The wind

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Draft

- Wind basics
- Drivers of the wind energy application
- The energy of the wind
- Dynamic simulation
- Wind forecast

The wind… … forms the surface

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The wind… … blows our hair

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The wind… … brakes the signes

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The wind… … moves the sailboats

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The wind… … destroys the forests

The wind… … forwards the snow

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The wind… … blows the flag

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The wind… … lifts our kite

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The wind… … dries our cloths

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And the wind… …bends the trees

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And the wind… …turns our propeller

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…but nobody can see it!

Windrose

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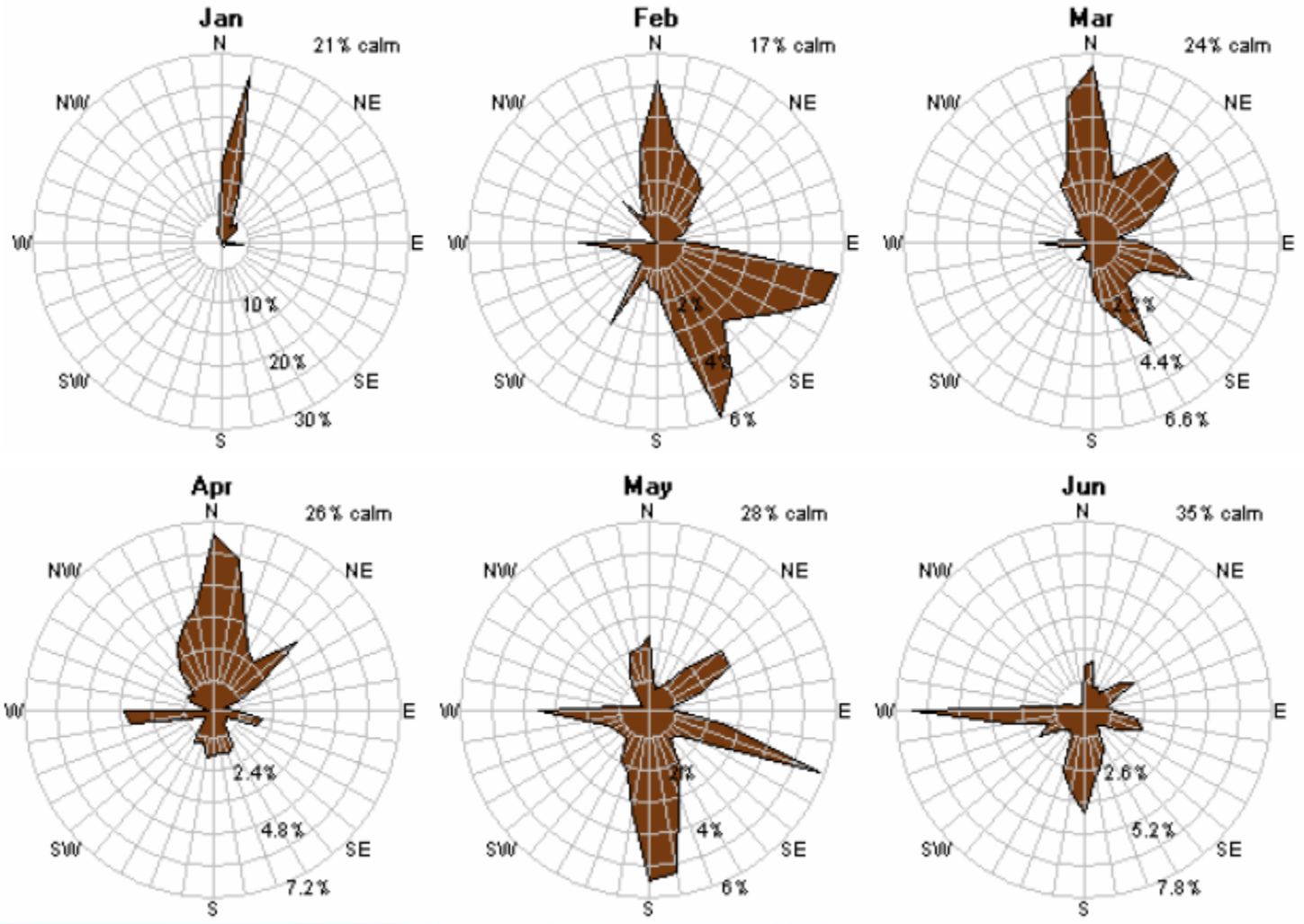

Windrose

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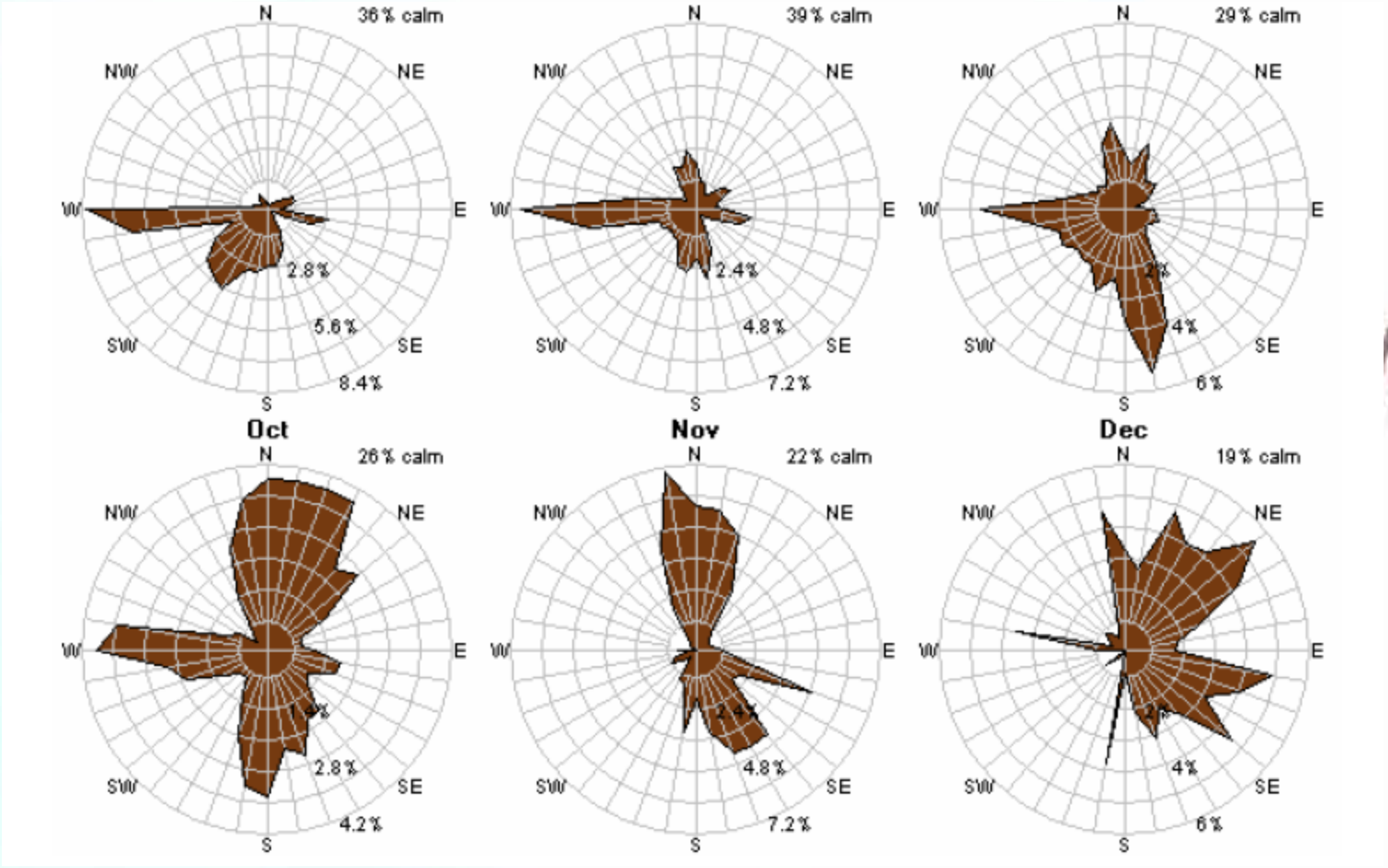
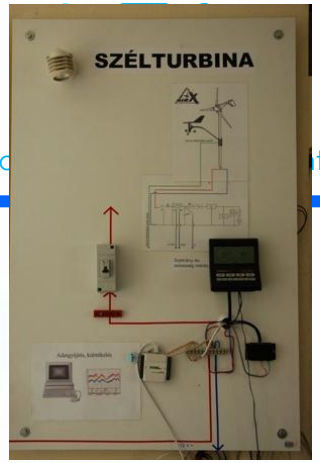
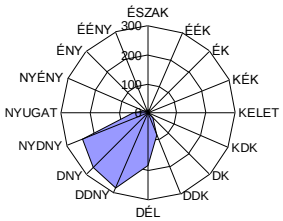
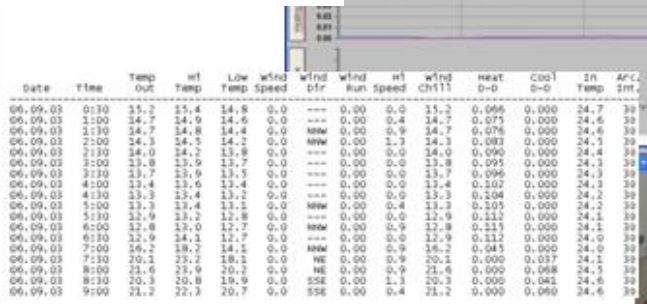


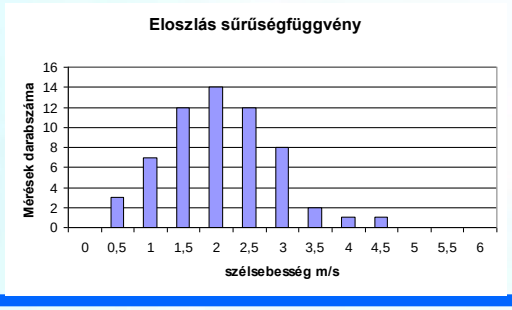
Wind turbine and measurement system

anemometer









Measurements

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Date	Time	Temp Out	Hi Temp	Low Temp	Wind Speed	Wind Dir	Wind Run	Hi Speed	Wind Chill	Heat D-D	Cool D-D	In Temp	Arc. Int.
06.09.03	0:30	15.2	15.4	14.8	0.0	---	0.00	0.0	15.2	0.066	0.000	24.7	30
06.09.03	1:00	14.7	14.9	14.6	0.0	---	0.00	0.4	14.7	0.075	0.000	24.6	30
06.09.03	1:30	14.7	14.8	14.4	0.0	NNW	0.00	0.9	14.7	0.076	0.000	24.6	30
06.09.03	2:00	14.3	14.5	14.2	0.0	NNW	0.00	1.3	14.3	0.083	0.000	24.5	30
06.09.03	2:30	14.0	14.2	13.8	0.0	---	0.00	0.0	14.0	0.090	0.000	24.4	30
06.09.03	3:00	13.8	13.9	13.7	0.0	---	0.00	0.0	13.8	0.095	0.000	24.3	30
06.09.03	3:30	13.7	13.9	13.5	0.0	---	0.00	0.0	13.7	0.096	0.000	24.3	30
06.09.03	4:00	13.4	13.6	13.4	0.0	---	0.00	0.0	13.4	0.102	0.000	24.3	30
06.09.03	4:30	13.3	13.4	13.2	0.0	---	0.00	0.0	13.3	0.104	0.000	24.2	30
06.09.03	5:00	13.3	13.4	13.1	0.0	NNW	0.00	0.4	13.3	0.105	0.000	24.2	30
06.09.03	5:30	12.9	13.2	12.8	0.0	---	0.00	0.0	12.9	0.112	0.000	24.1	30
06.09.03	6:00	12.8	13.0	12.7	0.0	NNW	0.00	0.9	12.8	0.115	0.000	24.1	30
06.09.03	6:30	12.9	14.1	12.7	0.0	---	0.00	0.0	12.9	0.112	0.000	24.0	30
06.09.03	7:00	16.2	18.2	14.1	0.0	NNW	0.00	0.9	16.2	0.045	0.000	24.0	30
06.09.03	7:30	20.1	23.2	18.1	0.0	NE	0.00	0.9	20.1	0.000	0.037	24.1	30
06.09.03	8:00	21.6	23.9	20.2	0.0	NE	0.00	0.9	21.6	0.000	0.068	24.5	30
06.09.03	8:30	20.3	20.8	19.9	0.0	SSE	0.00	1.3	20.3	0.000	0.041	24.6	30
06.09.03	9:00	21.2	22.3	20.7	0.0	SSE	0.00	0.4	21.2	0.000	0.060	24.6	30

Simple windrose

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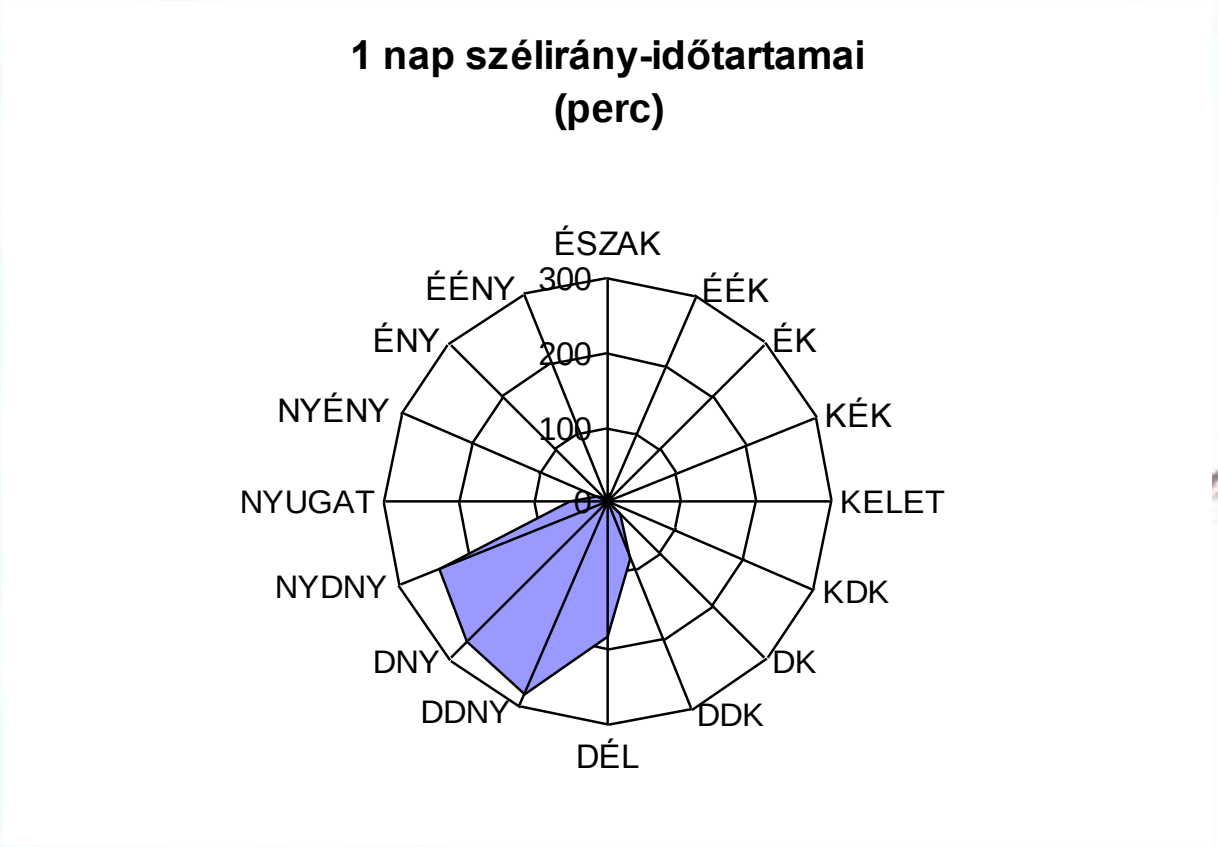

Speed-Weighted windrose

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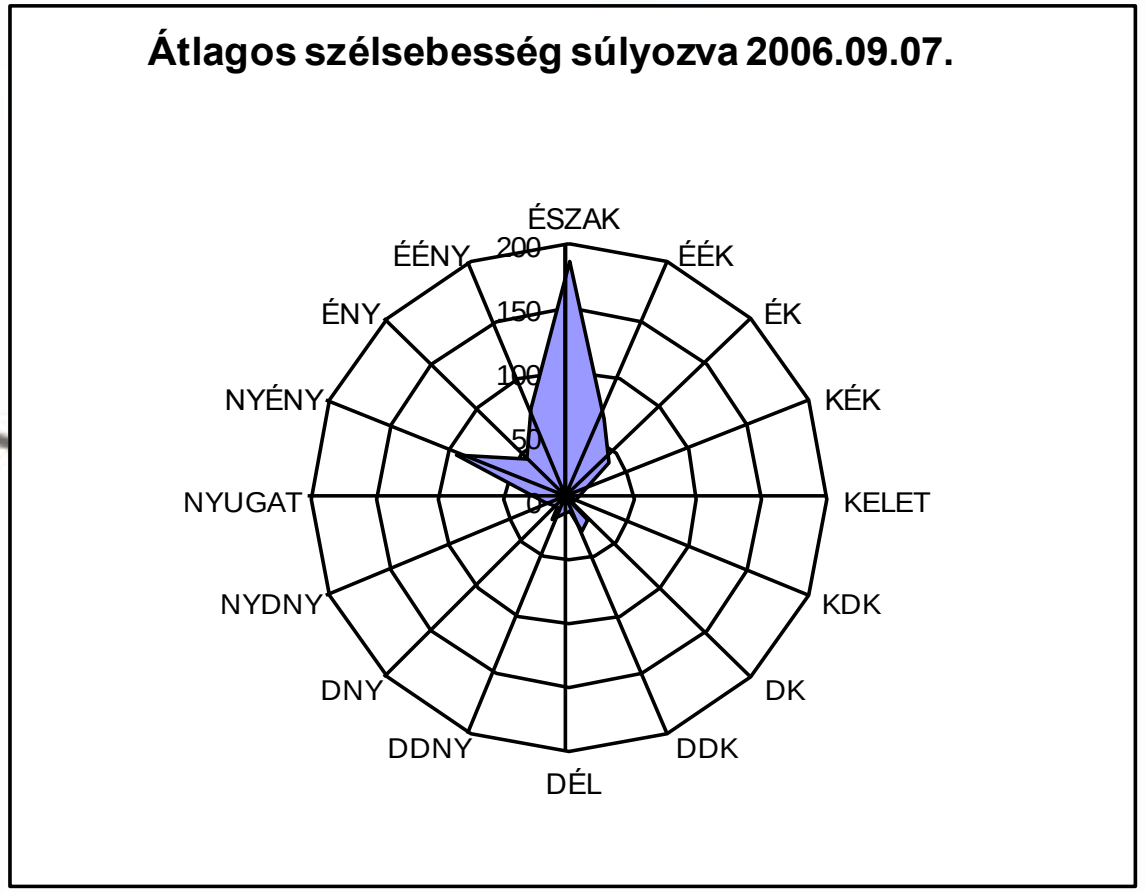
- Direction?
- Average speed?
- Energy?



Main winter directions

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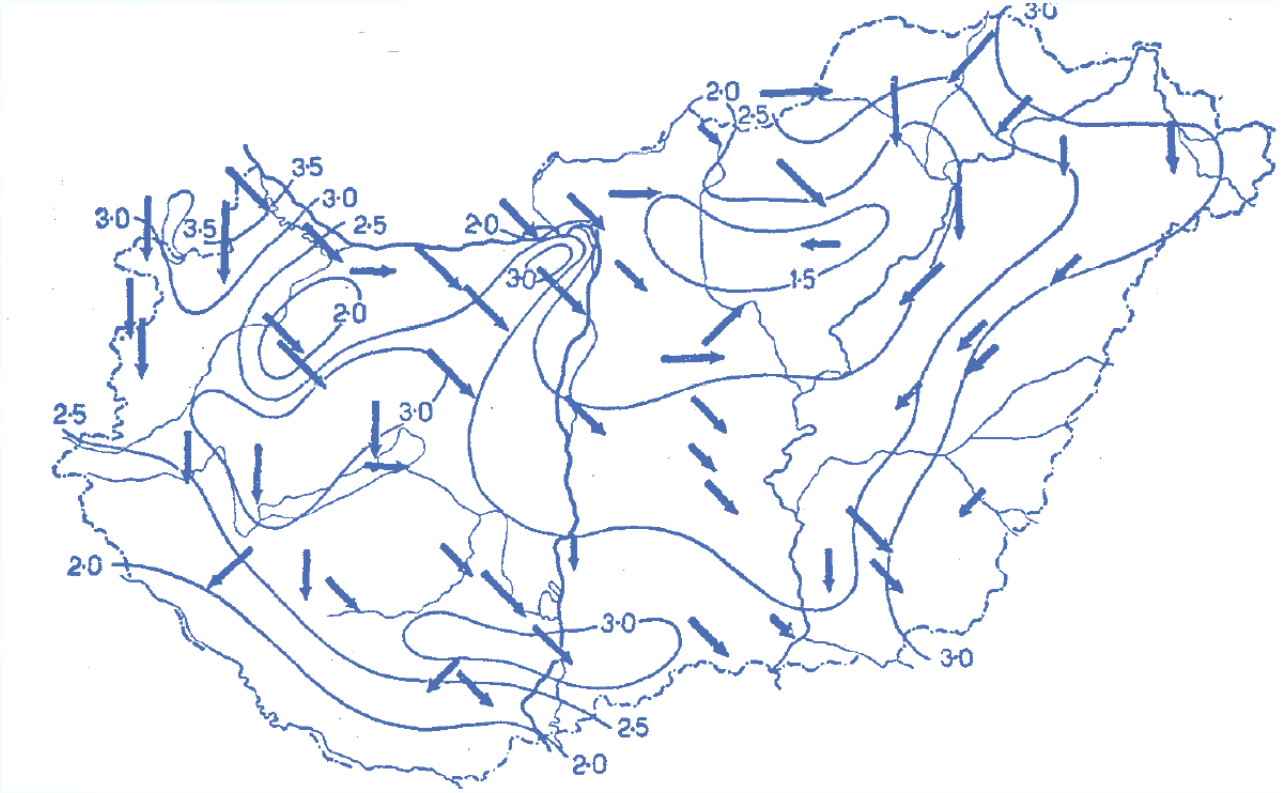

Main yearly directions

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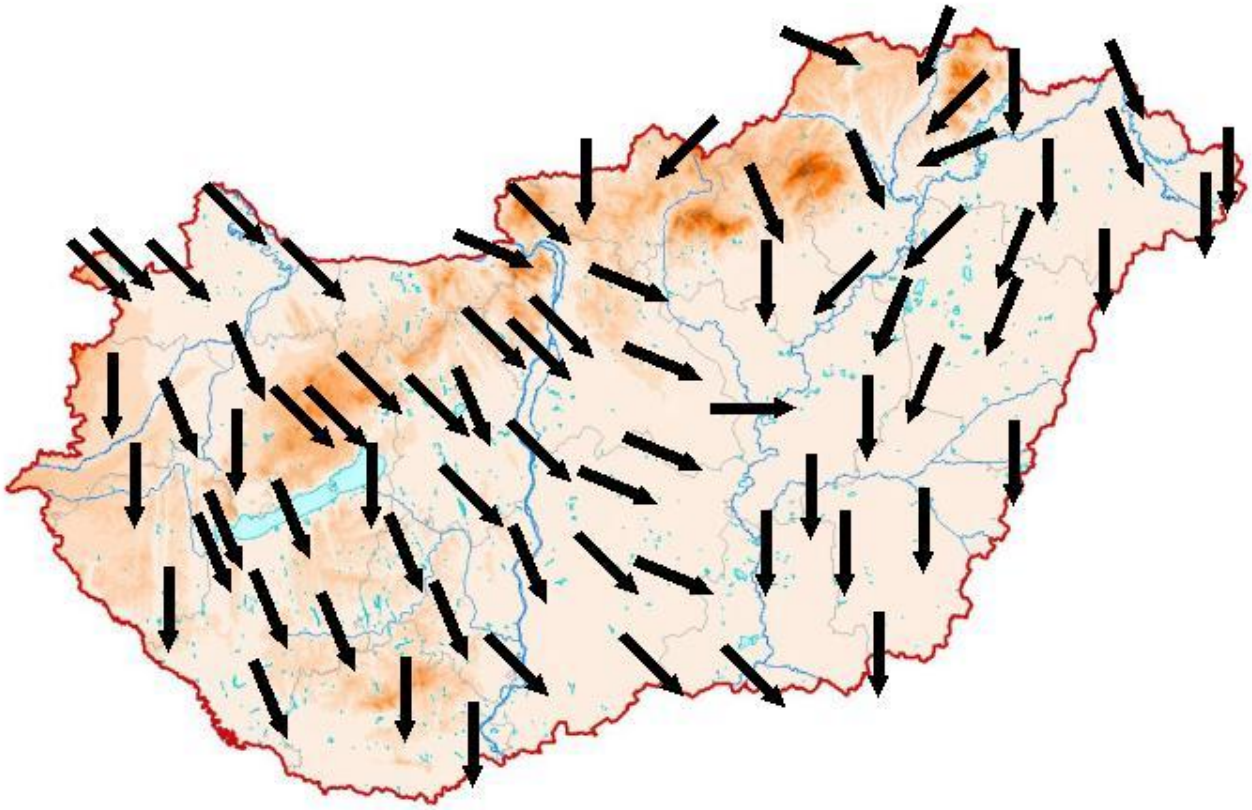

Wind (speed) map for 10 m heights

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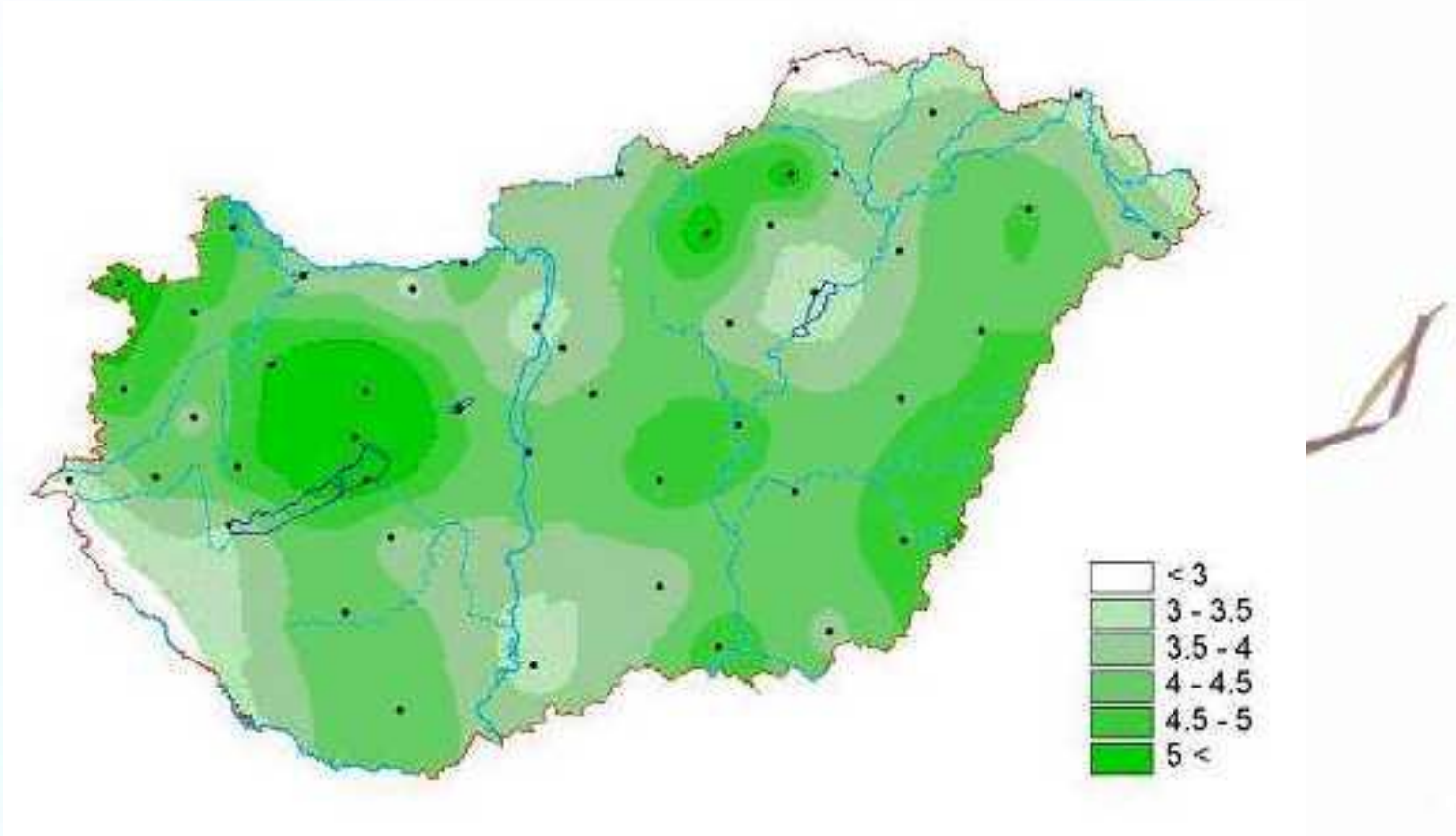

Wind (speed) map for 75 m height

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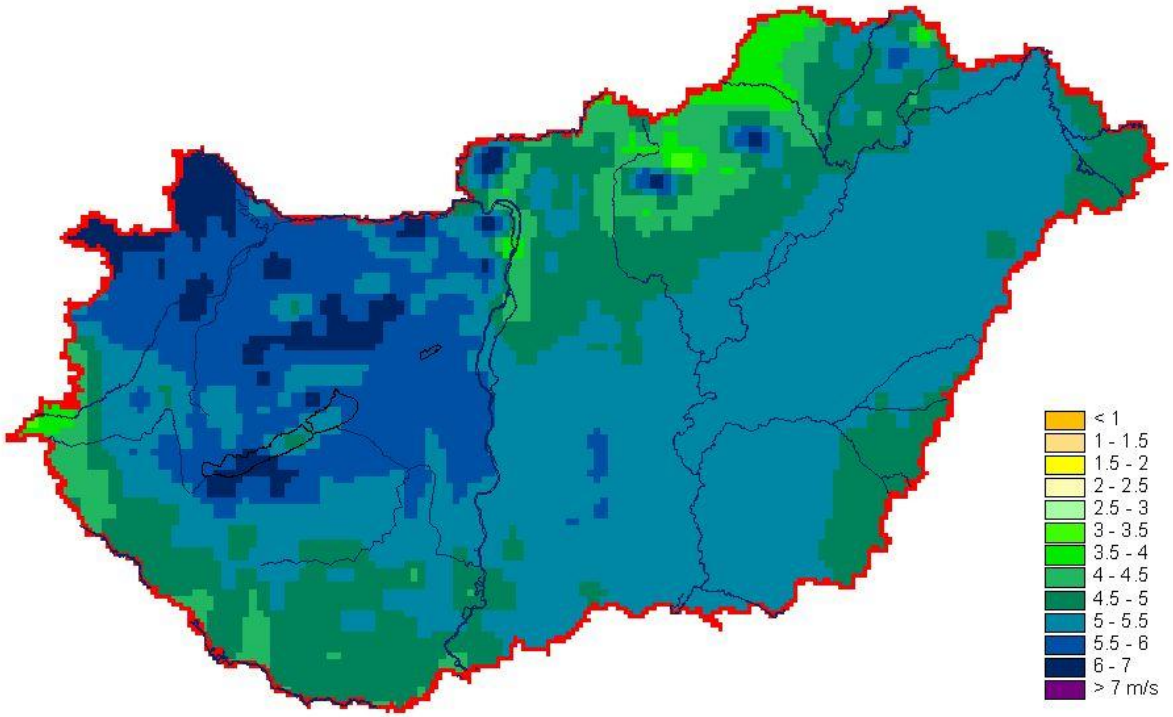

Daily wind course in diff. heights

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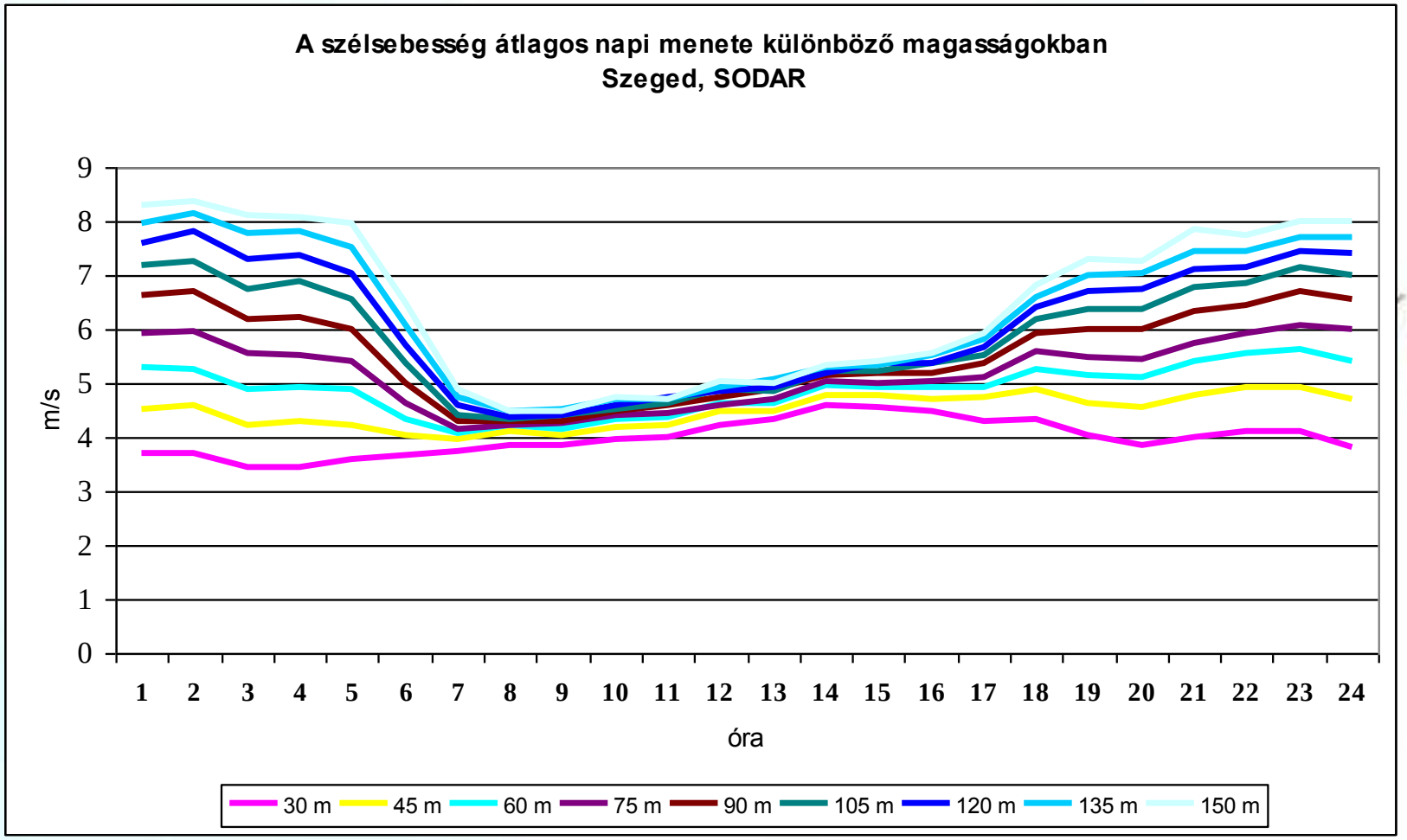

Upscaling

- Measurements or calculations on different heights
- Upscaling – continuous formula to define the windspeed in other heights
- e.g. Hellmann equation

$$u_z = u_m \left(\frac{z}{z_m} \right)^a \quad [\mathrm{m\,s^{-1}}]$$

Local wind profile

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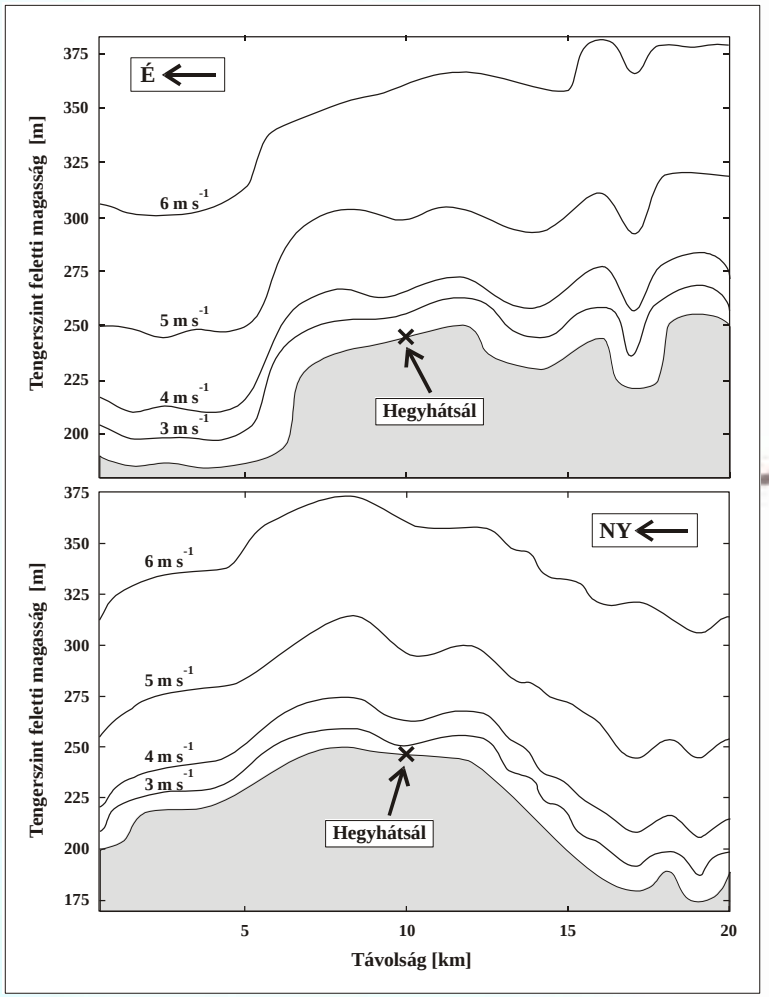

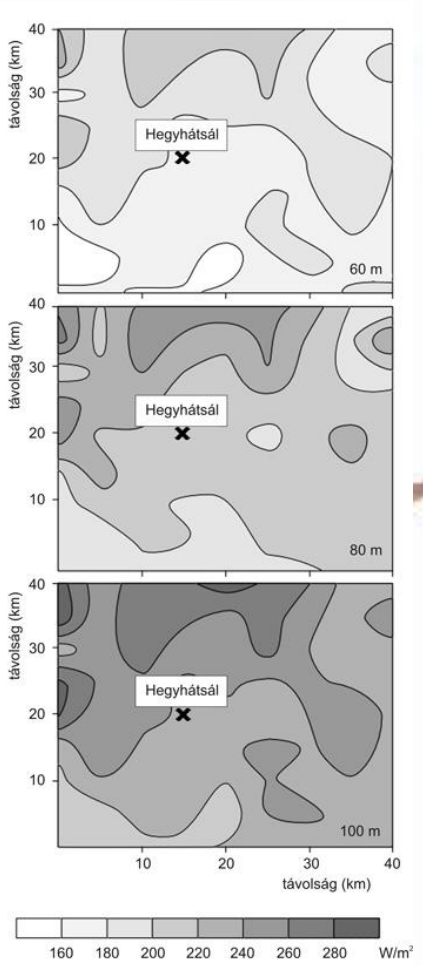

Global windforecast services

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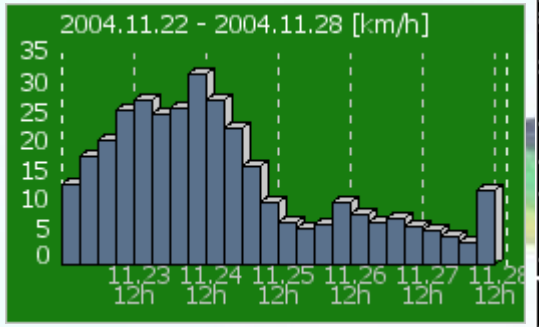

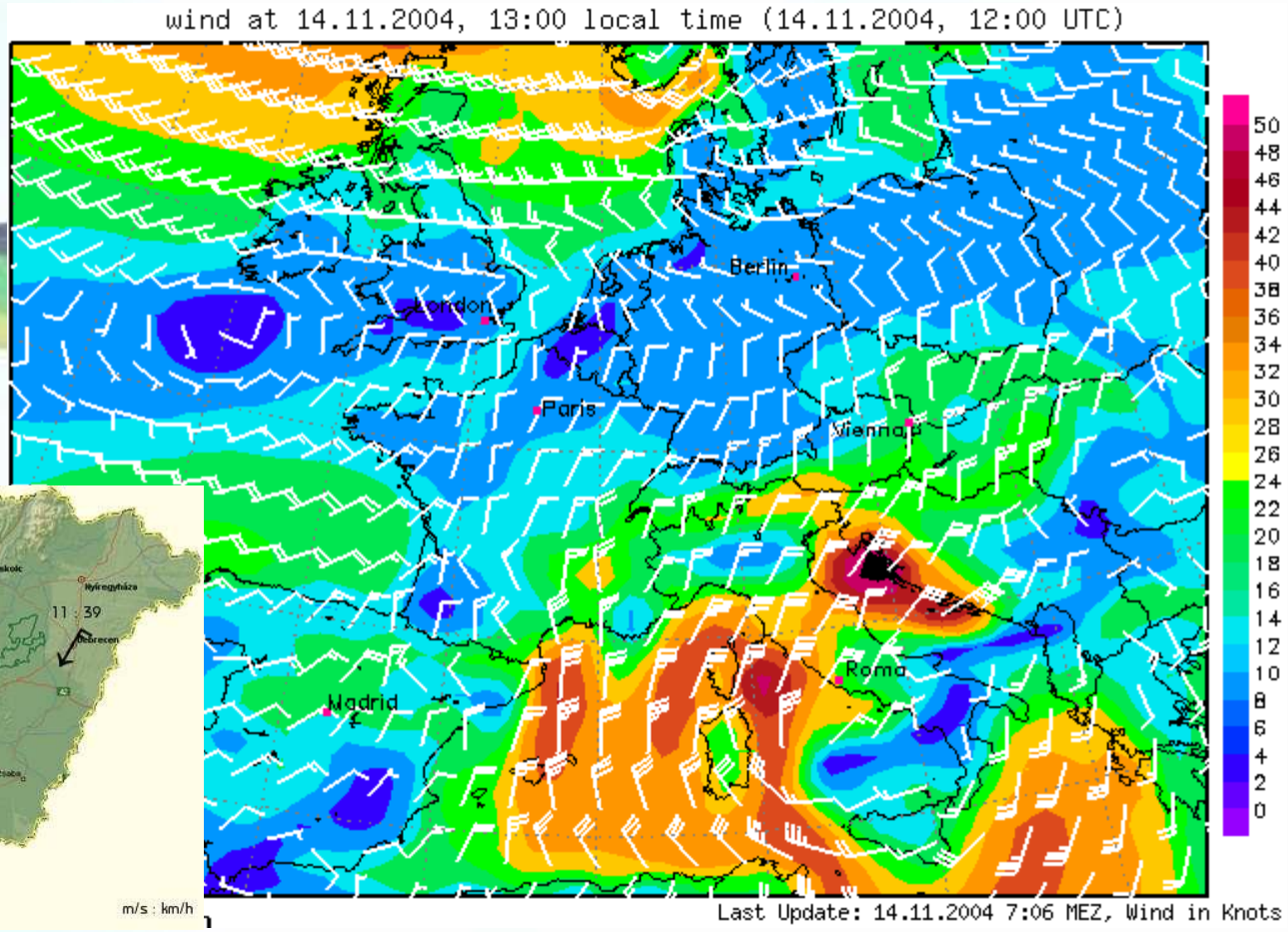

www.met.hu

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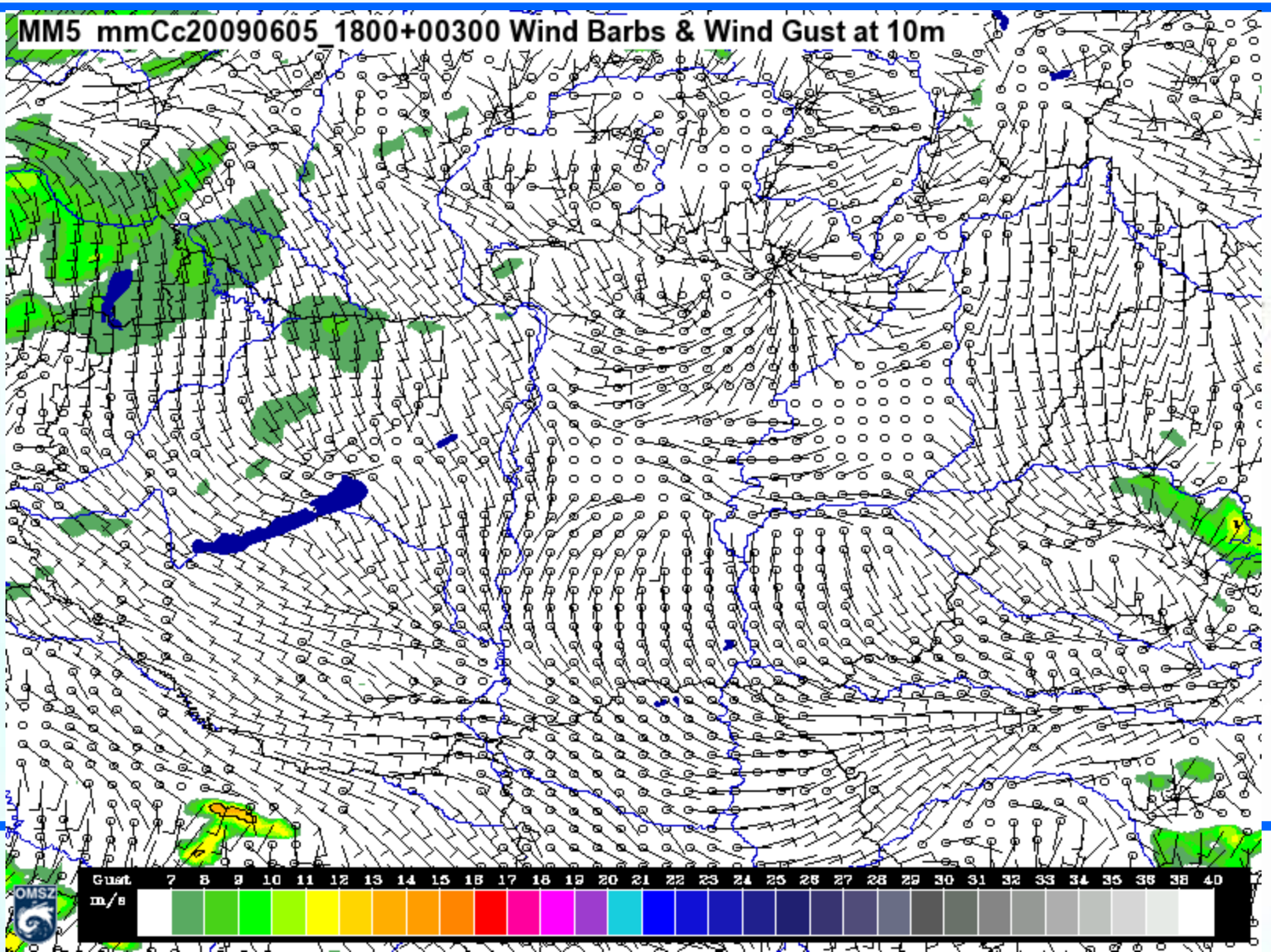

On-line: http://www.idokep.hu

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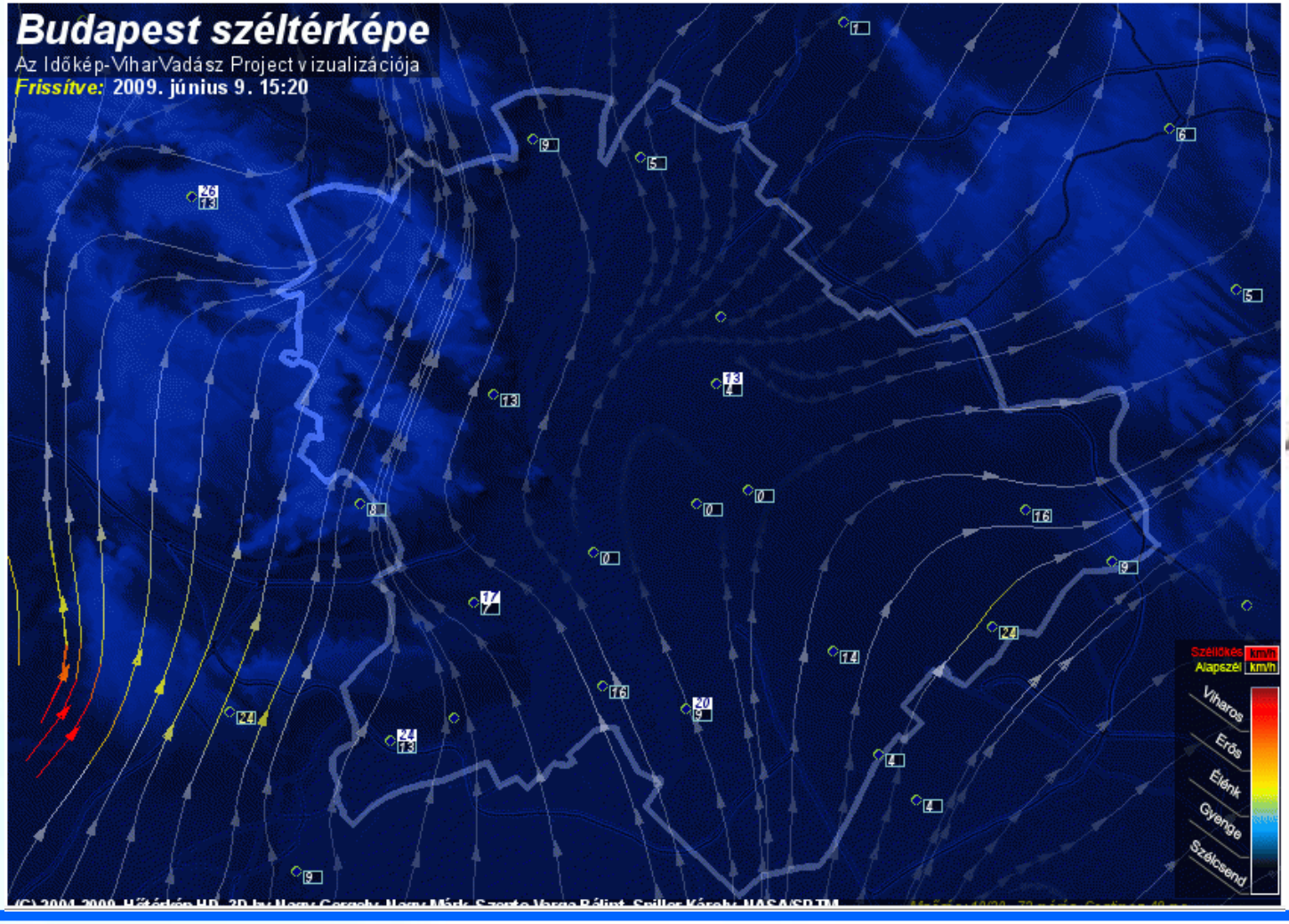

Historical data

(http://www.met.hu/megfigyelesek/index.php?v=Budapest)

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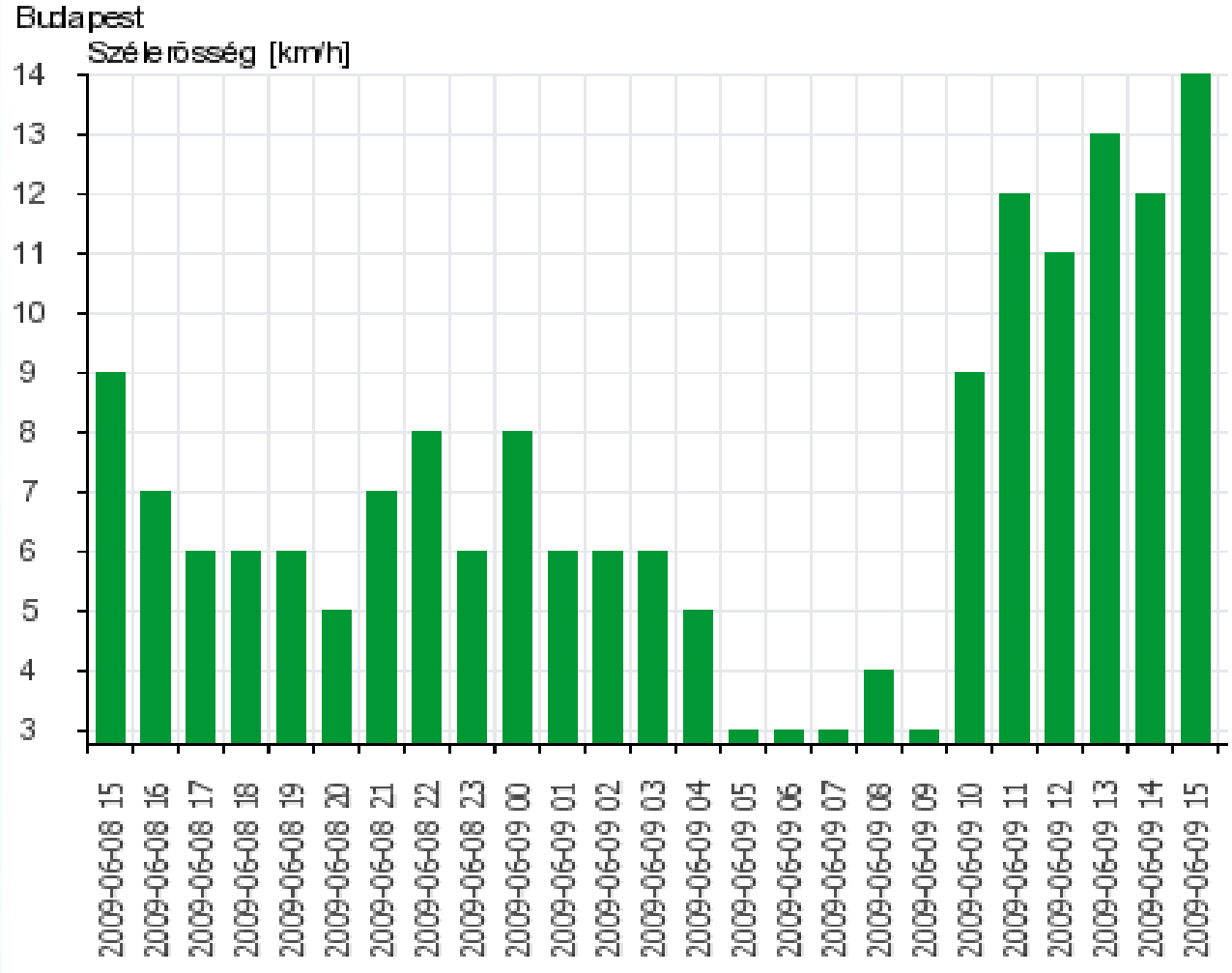

Global models

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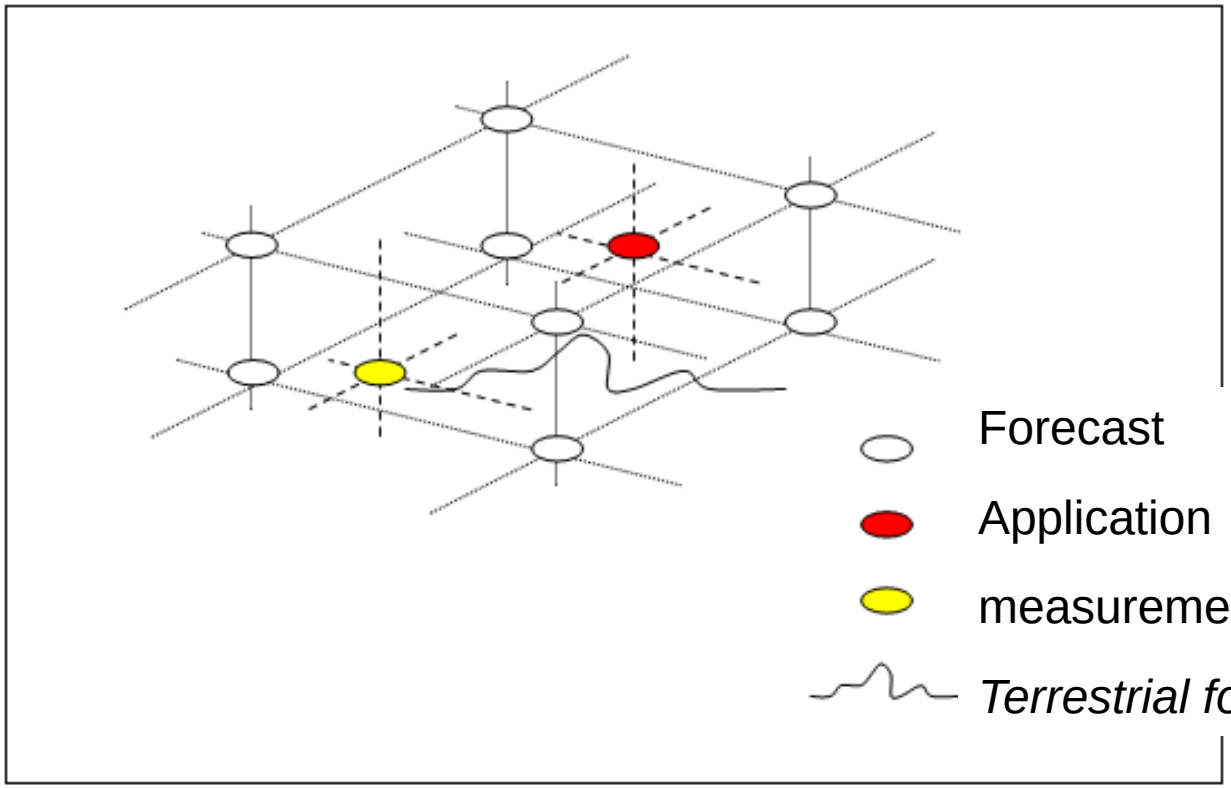
- Supercomputing
- 27 km -> 2,5 km cubes
- Differential equations system

But

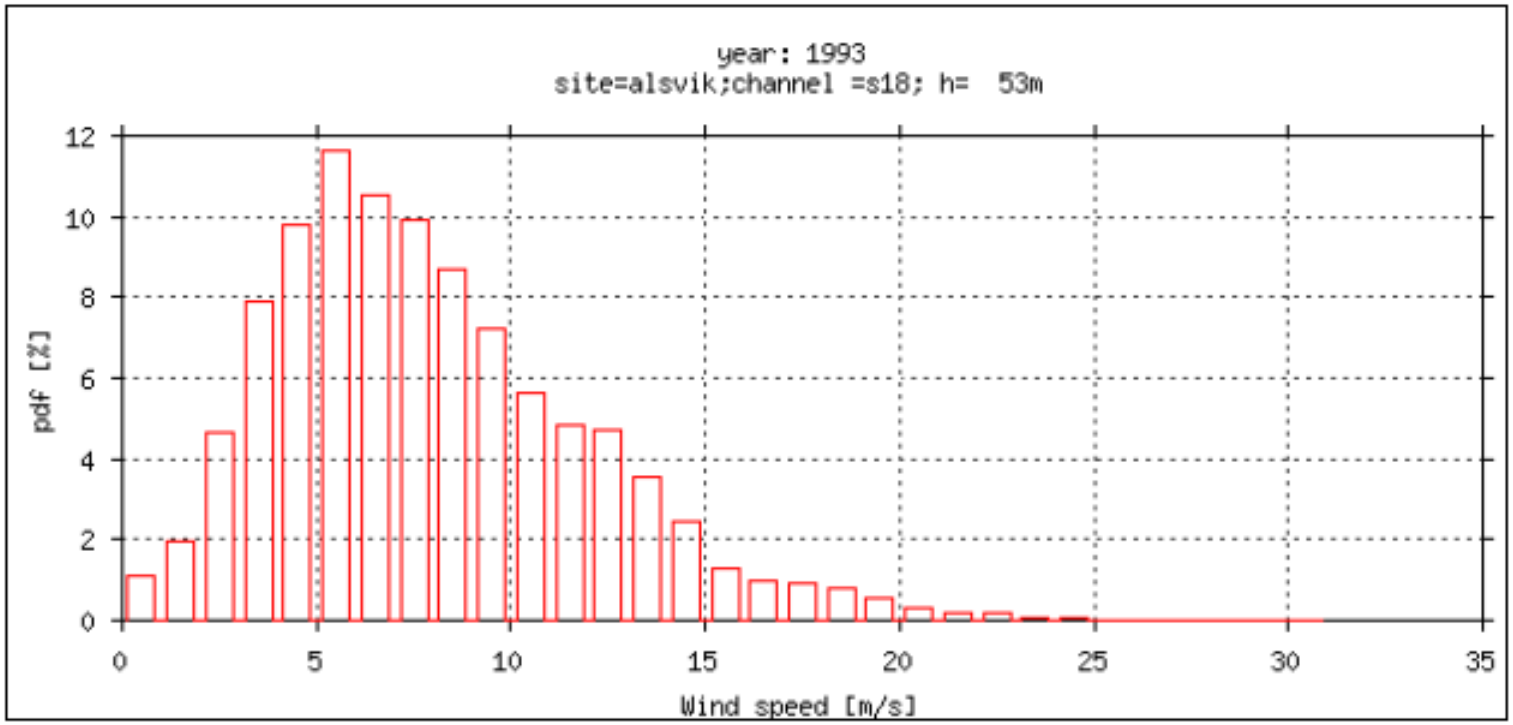
- Different measurement points
- Different application points



Professional services

- Numerical weather forecasts
- Horizontal and vertical interpolation
- Wind Atlas Analysis and Application Program + PARK modell
- Statistical elements
- Meteorological models (e.g. ALADIN, MEANDER), other sources (ECMWF, MM5, HIRLAM, stb.)
- Result presentation by heights or by isobar?

Statistical approach



Distribution of wind speeds, measured at Alsvik, Sweden, 1993.

Weibull distribution

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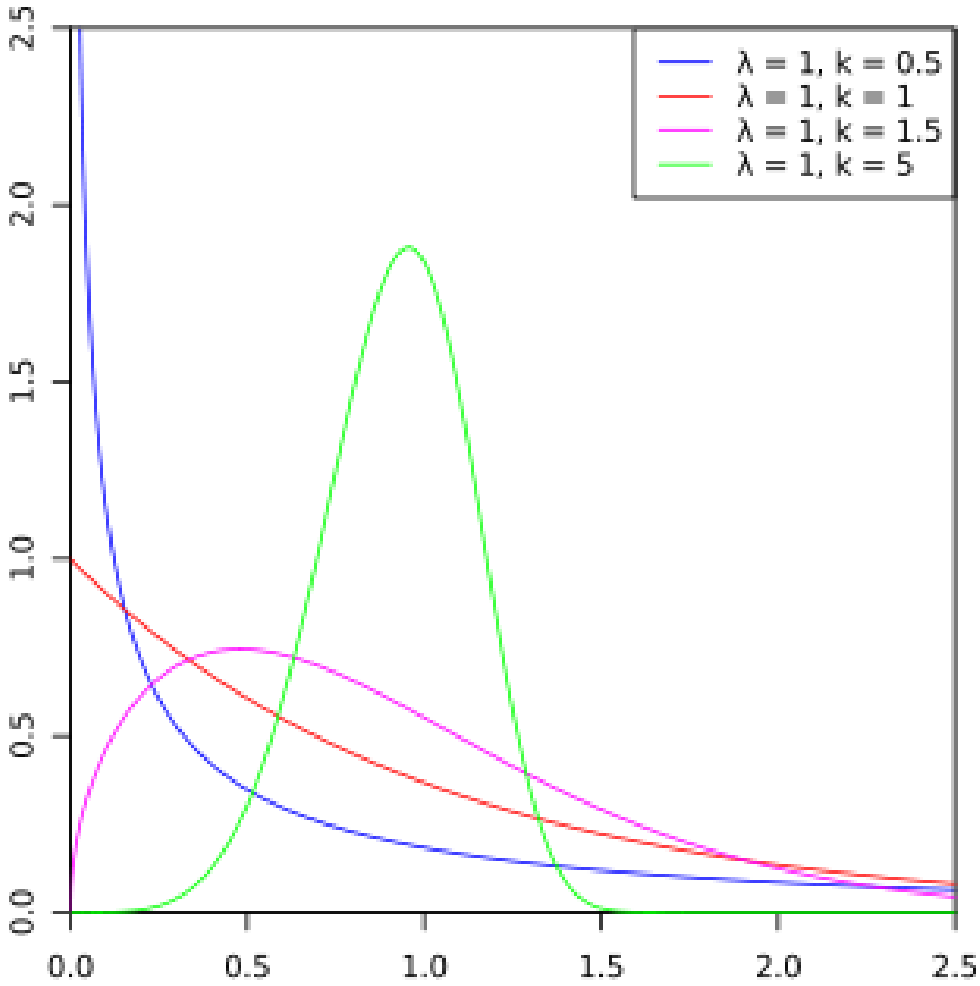
$$f(x;\lambda,k) = \begin{cases} \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k} & x \geq 0, \\ 0 & x < 0, \end{cases}$$



Local direction changes

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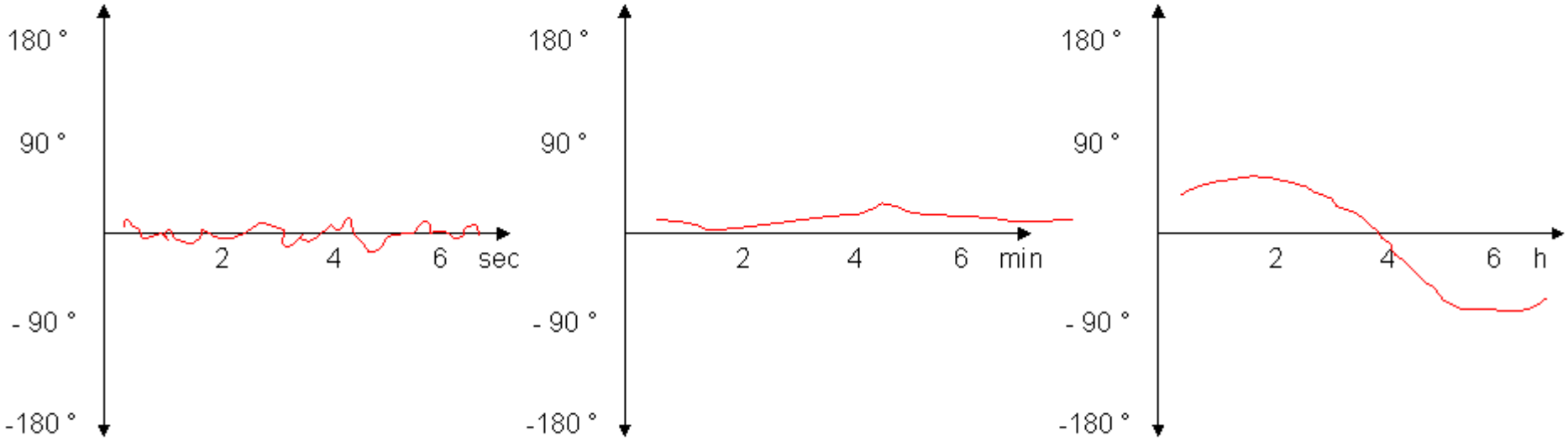

Local speed changes

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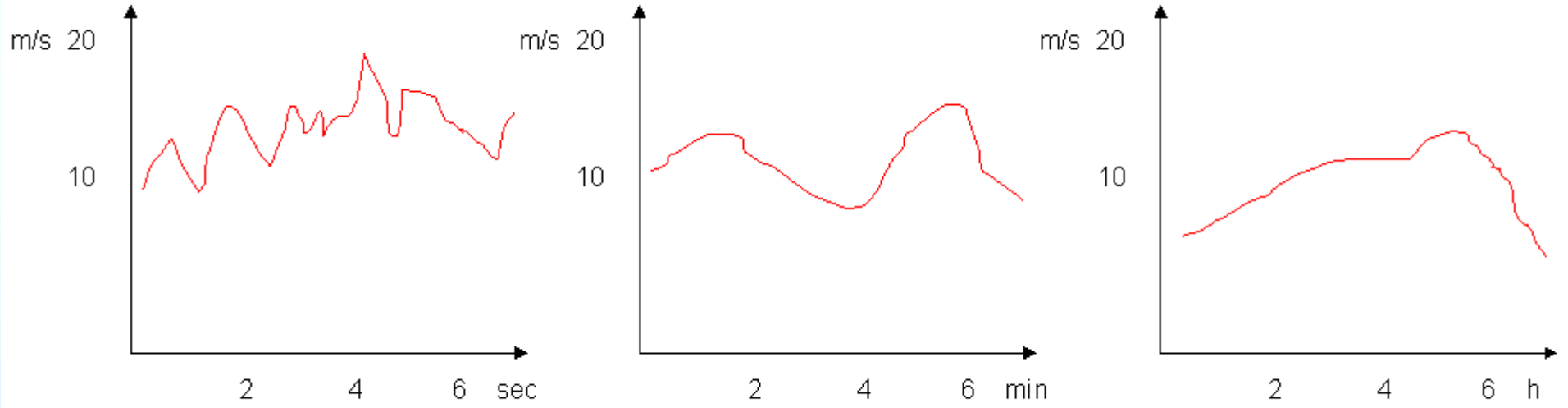

Speed changes + direction changes = turbulence

Turbulencies

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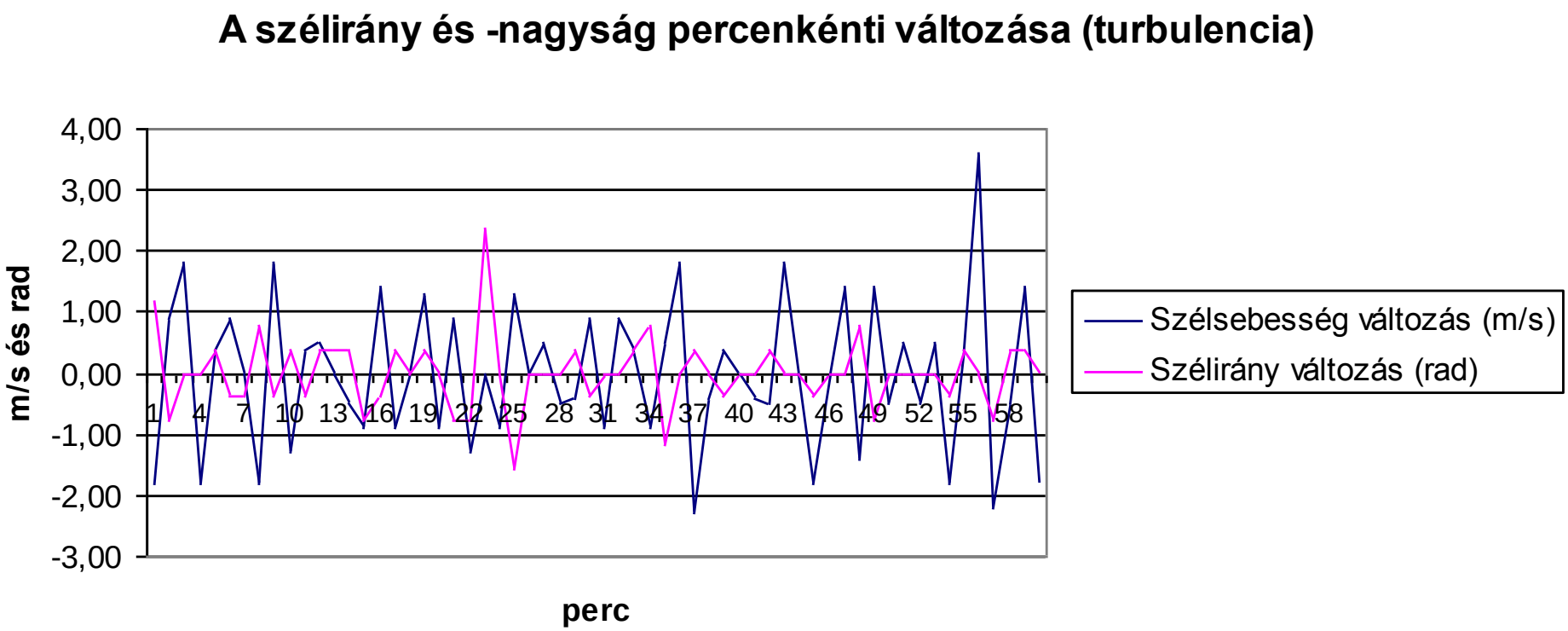

Local wind speed tower measurements in a wind park, during 4 min, in the range 6-10 m/s

(data from: M*ov-R H1 Szélerőmű Kft., Hungary)*

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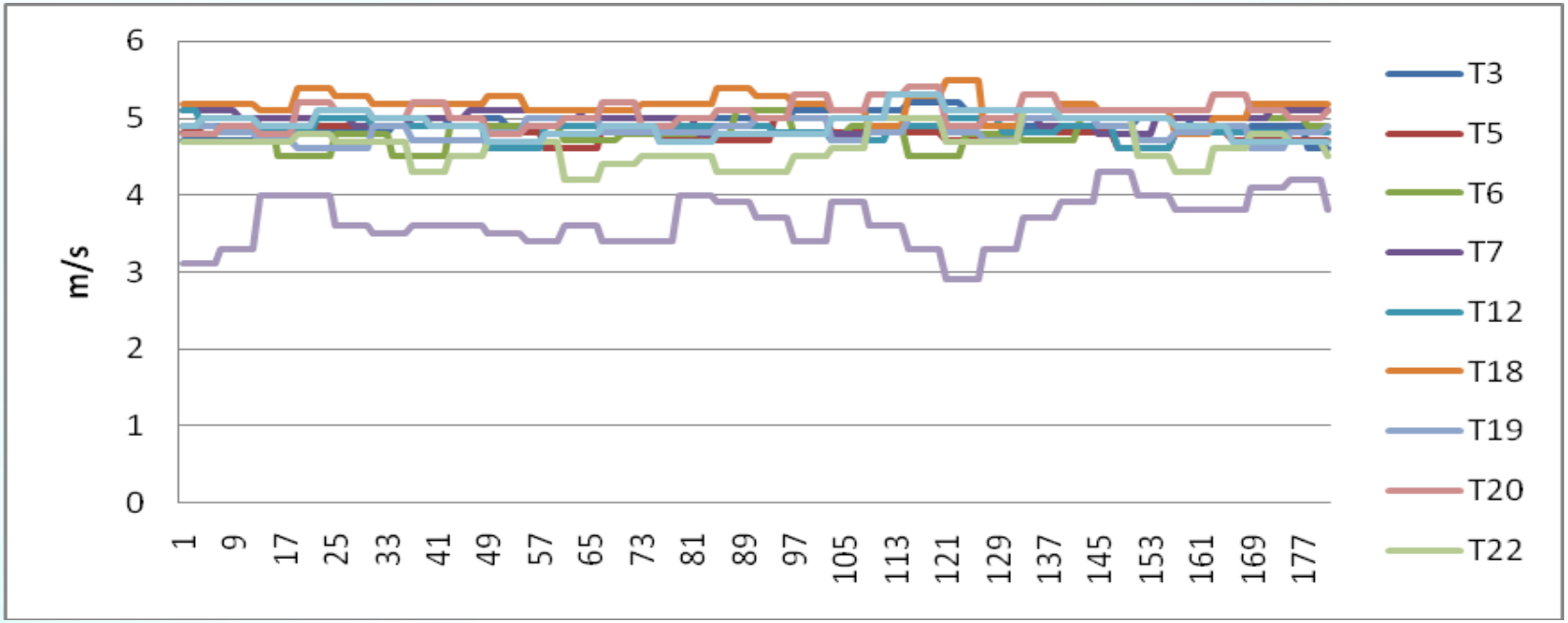

Local wind speed tower measurements in a wind park, during 4 min, in the range 3-6 m/s

(data from: Mov-*R H1 Szélerőmű Kft., Hungary)*

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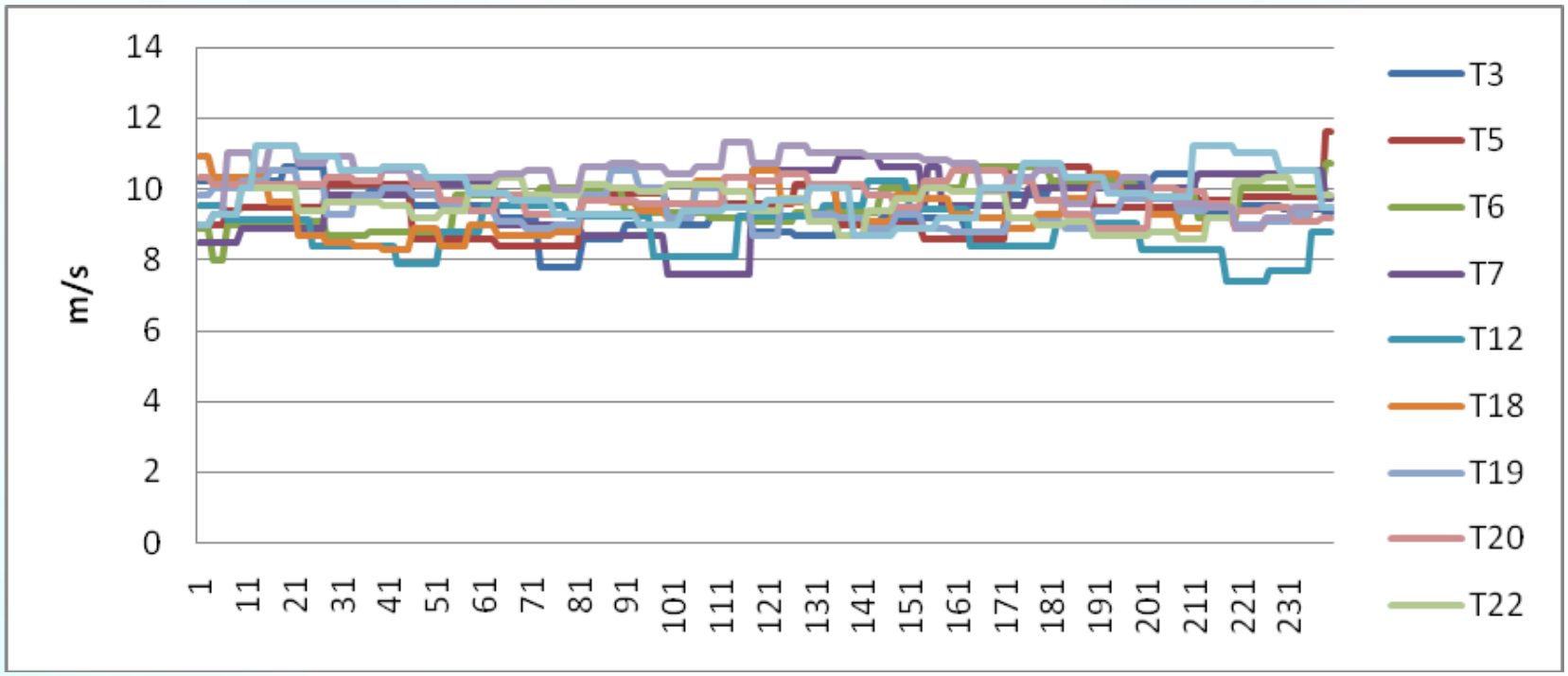

Local wind speed tower measurements in a wind park, during 4 min, over 10 m/s

(data from: M*ov-R H1 Szélerőmű Kft., Hungary)*

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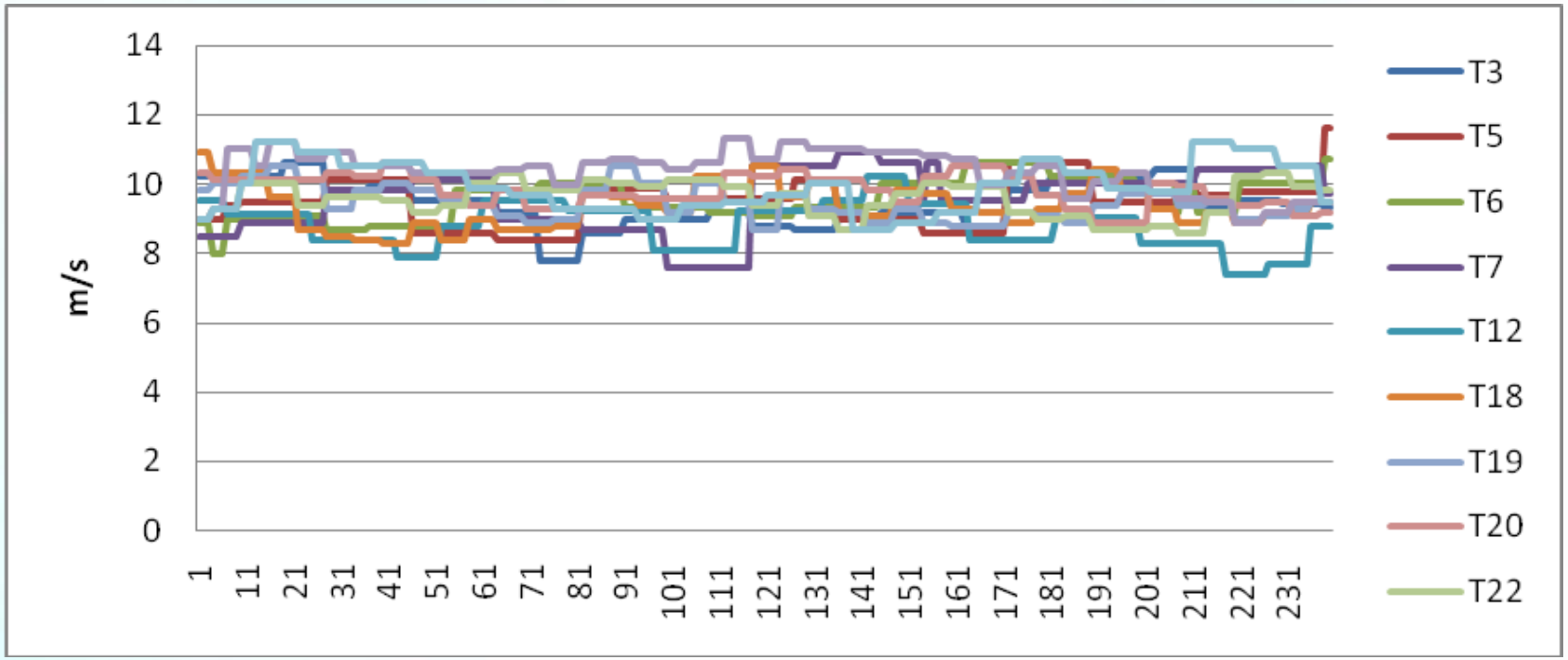

Spread over of the wind energy application

Fig.Global cumulative installed wind capacity 1996-2010

Global Wind Energy Council 2010 (GWEC)

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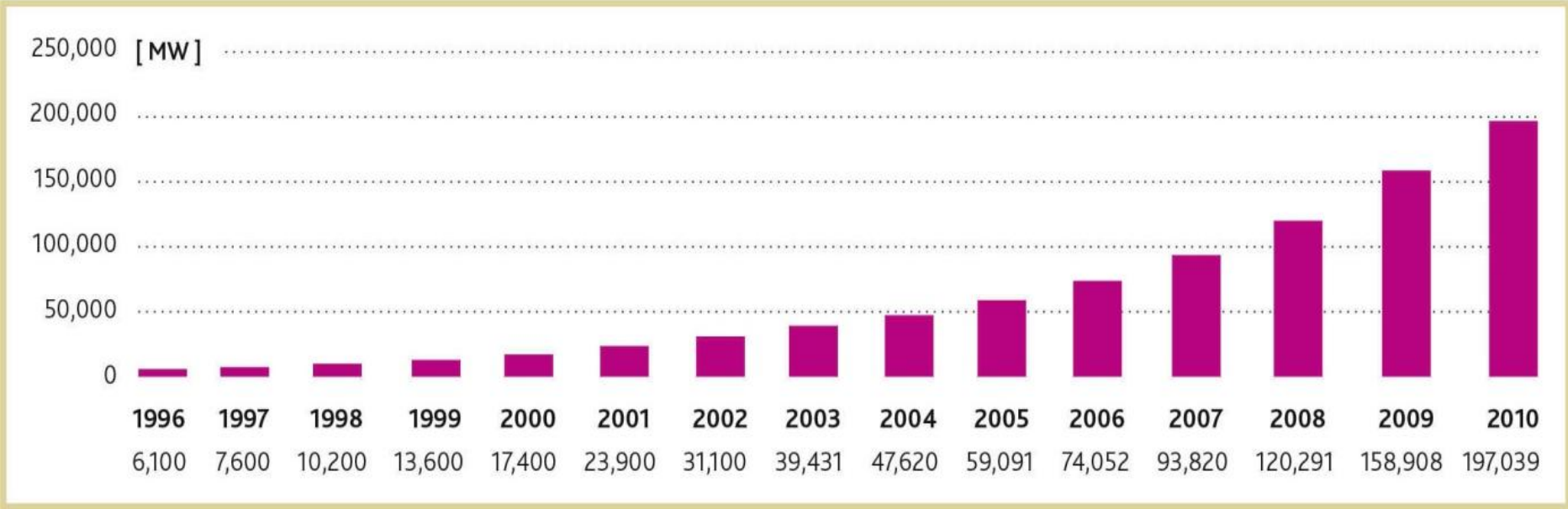

Windpower capacity in Europe, 2006, MW

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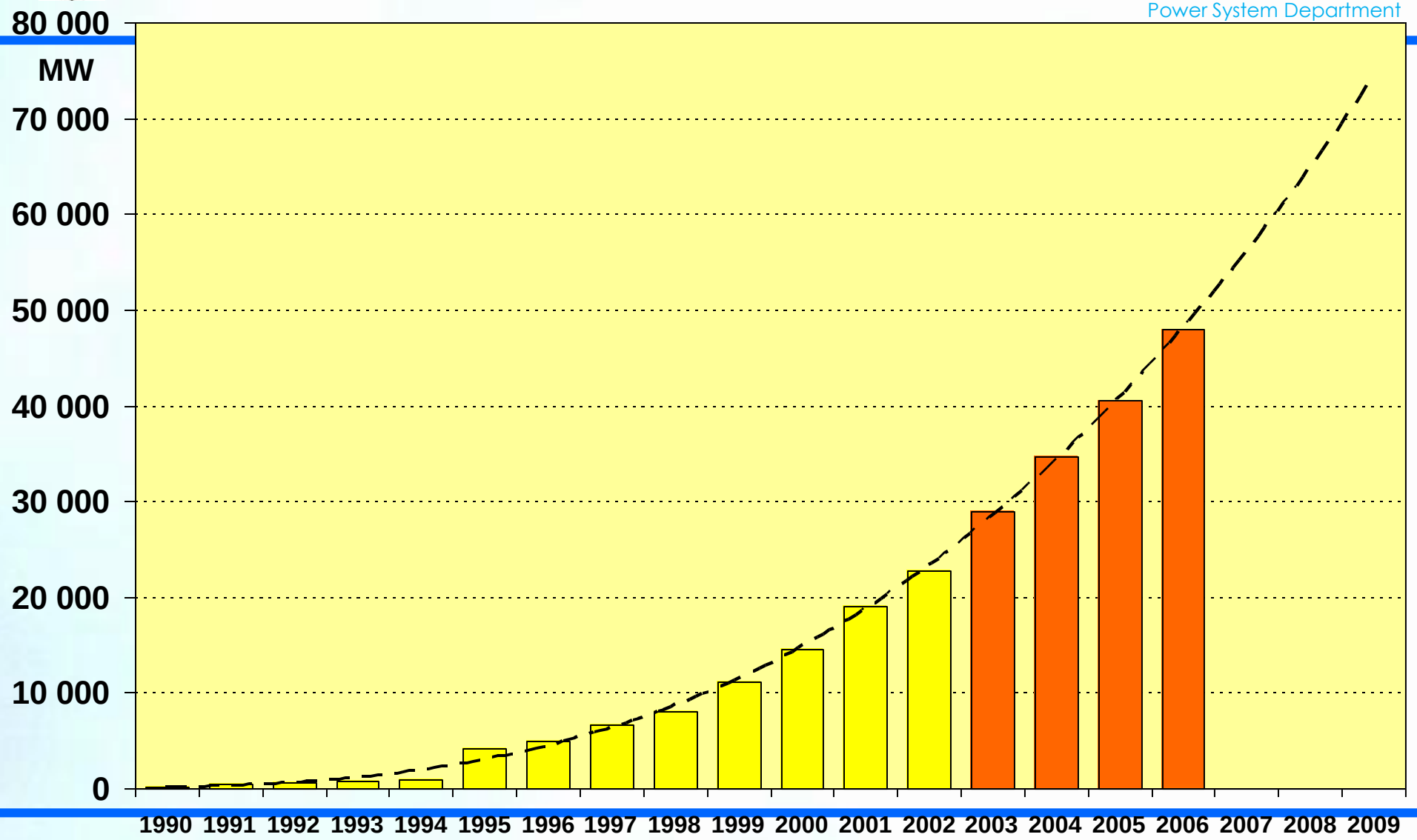

Forrás: www.ewea.org

Wind energy application in Europe

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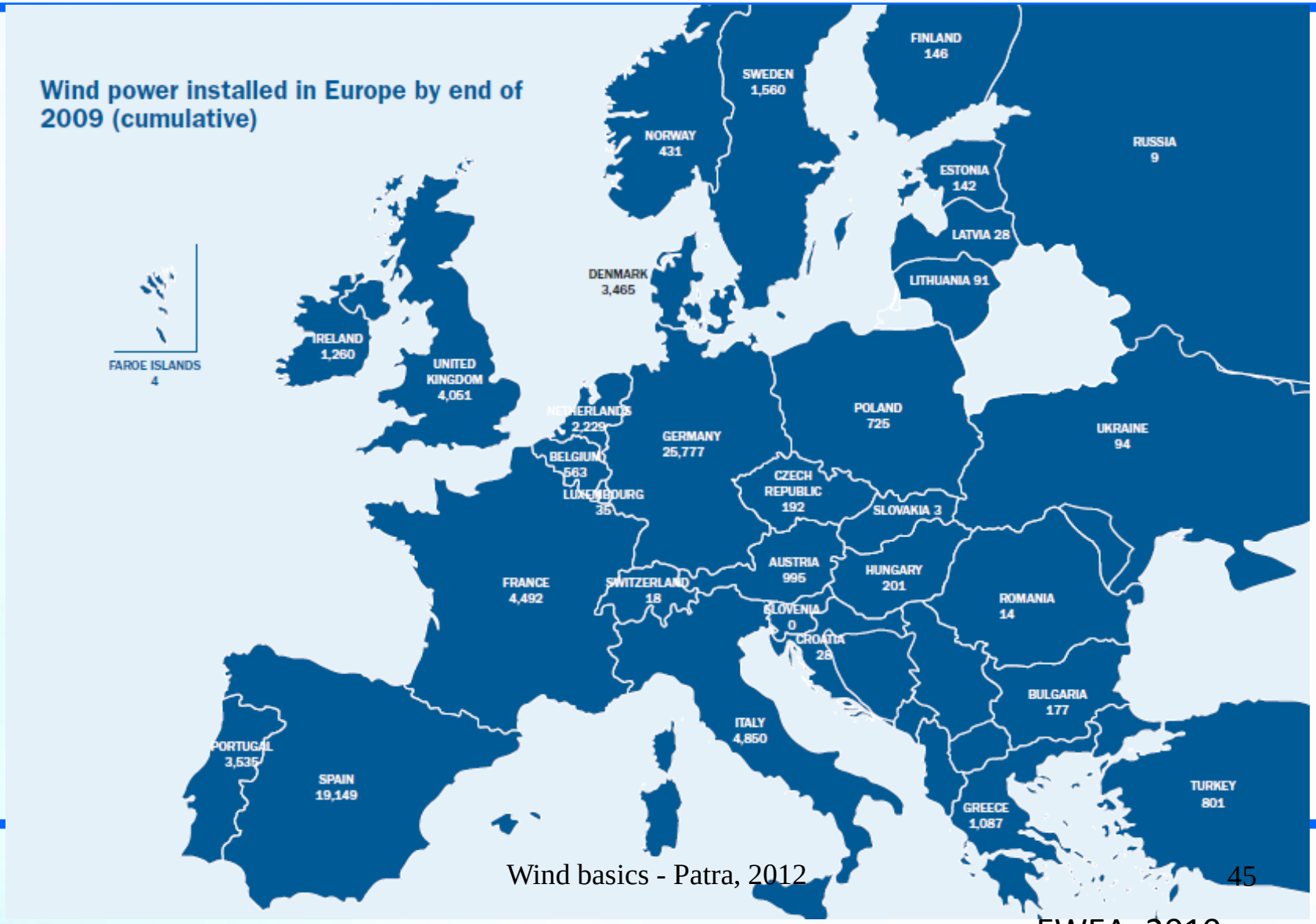
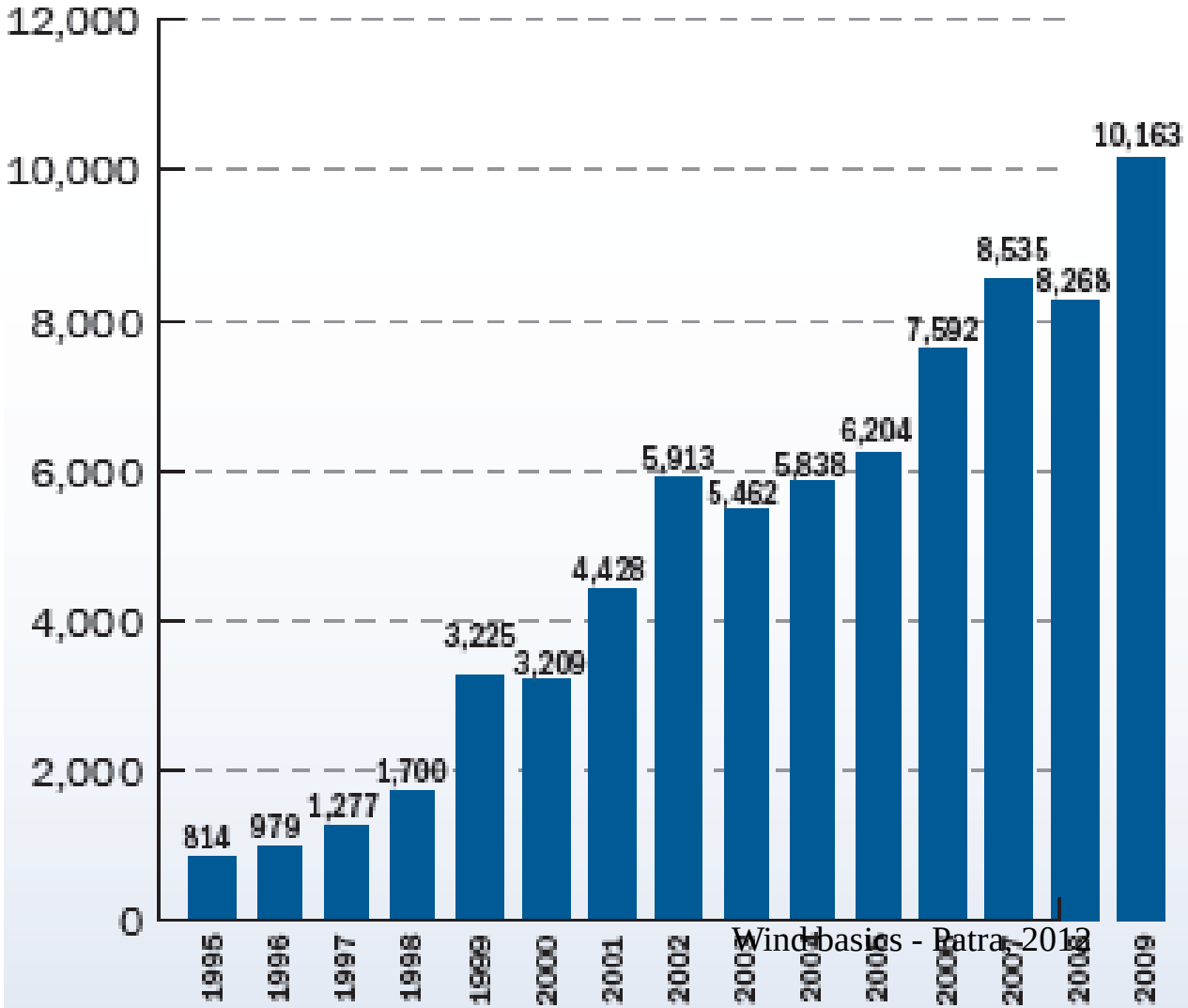


EWEA, 2010

Yearly built in wind capacities in Europe



2009
9581MW
onshore
582MW
offshore

EWEA, 2010

Repowering

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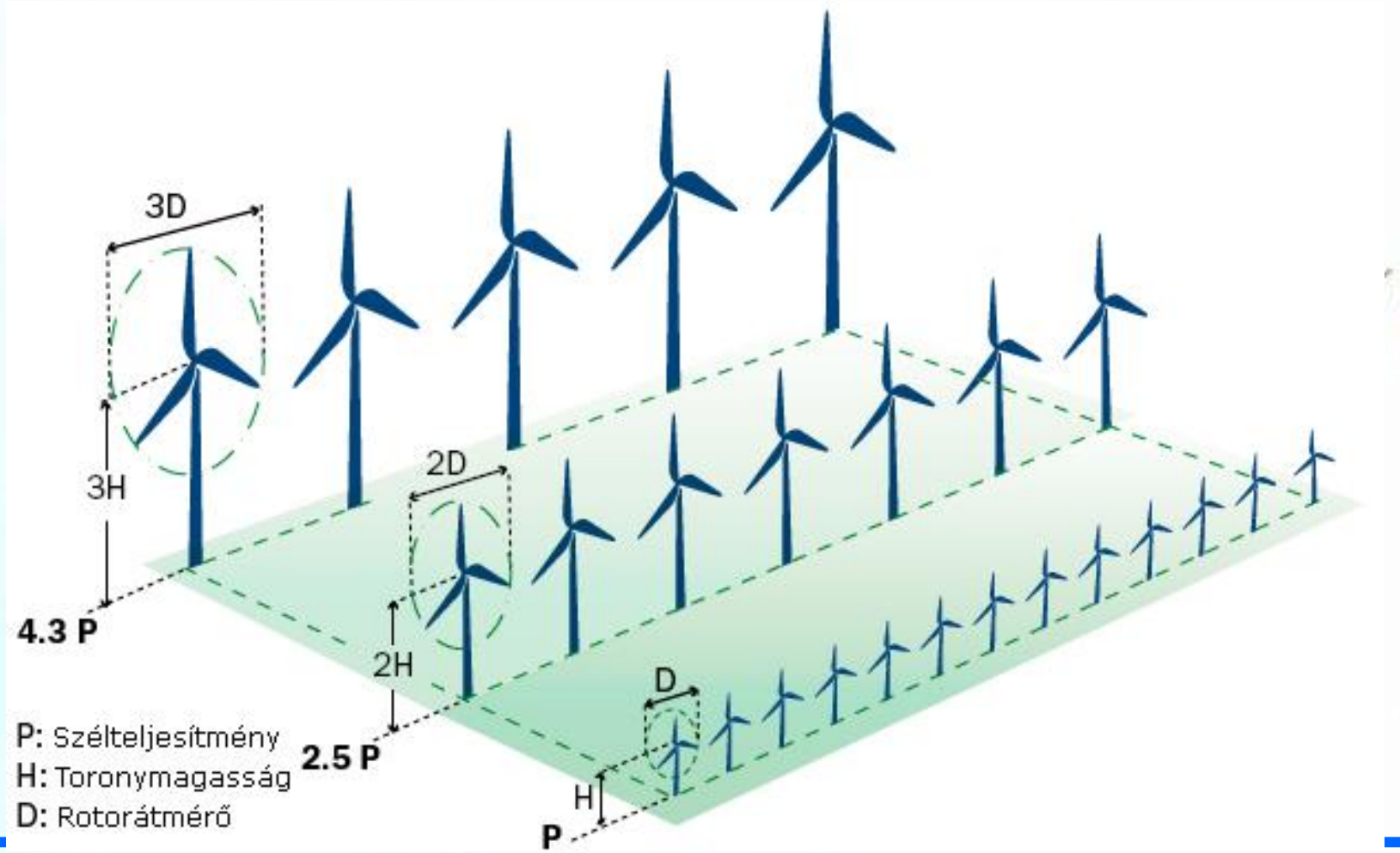


Some drivers of the windenergy business

- Growing demand for electricity
- EU directives
- Subventions
- Sustainability
- Reduction of CO_2 emisson
- Green investment boom (ROI 4-5 years)
- Employment, etc.

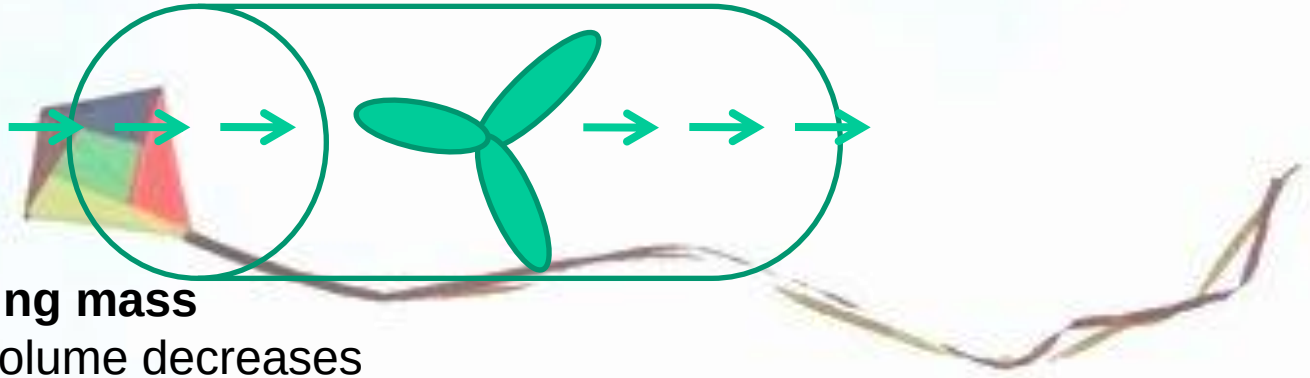
Catching the wind energy

Simple energy modells

1. **Tube model**

v - speed, V - volume do not changes

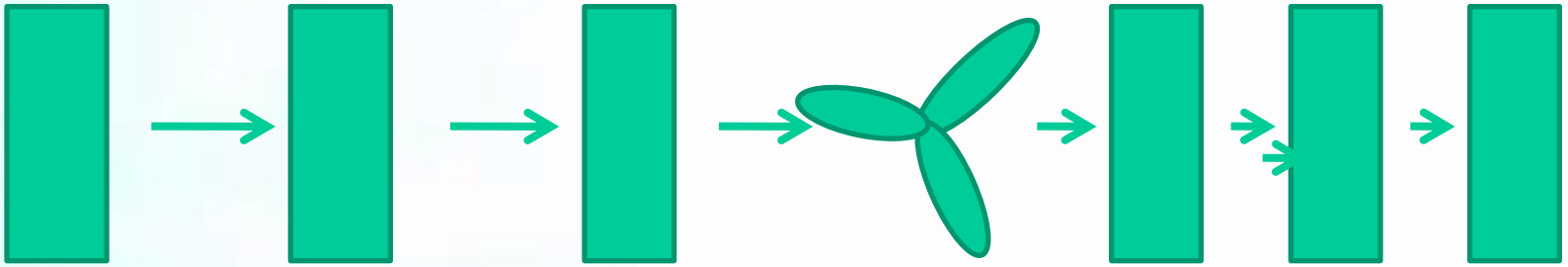
P – pressure, T – temperature decreeases



2. **Deccelerating mass**

v - speed, V - volume decreases

P – pressure, T – temperature do not changes



Reality: v, V, P, T - changes

Power of the wind (moving mass model)

$$P = 0{,}5\ \rho\ A\ v^3\ \eta$$

where

- **P** = mechanical (~electrical) power of the wind turbine,
- **ρ** = 1,29 kg/Nm^3 – density of the air,
- **A** = r2 π = d2 π / 4 area swept by the rotor blades (r is the length of the blade, d = 2 r diameter of the rotor),
- **v** = wind speed,
- **η** = efficiency of the rotor (theoretical max. is 60 %, practically 10-30 %).

Obstacle and the flowing air

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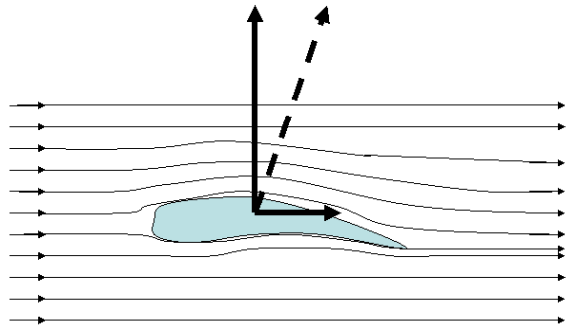
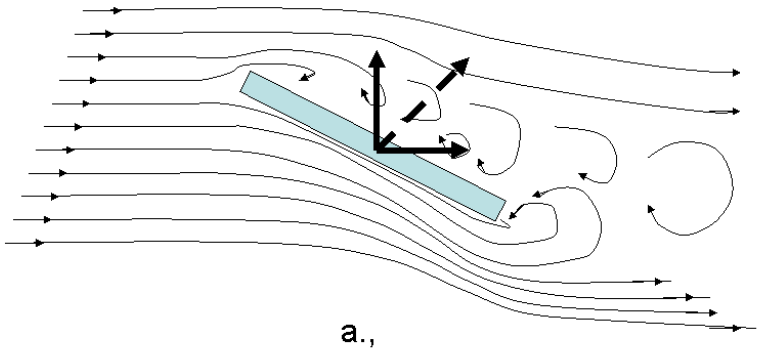
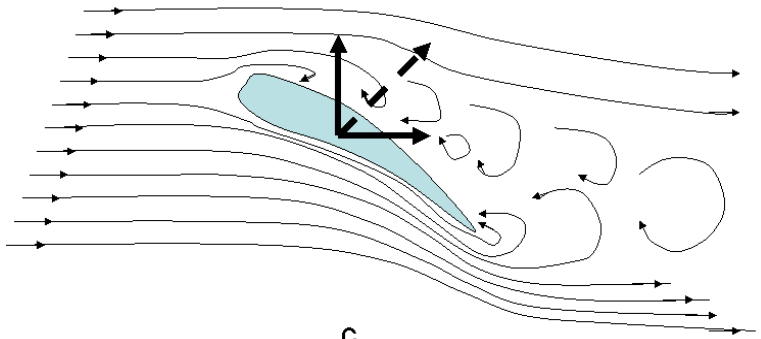
- a - turbulent
- b - laminal
- c – turbulent (stall)



b.,



a.,



c.,

The possible energy conversion

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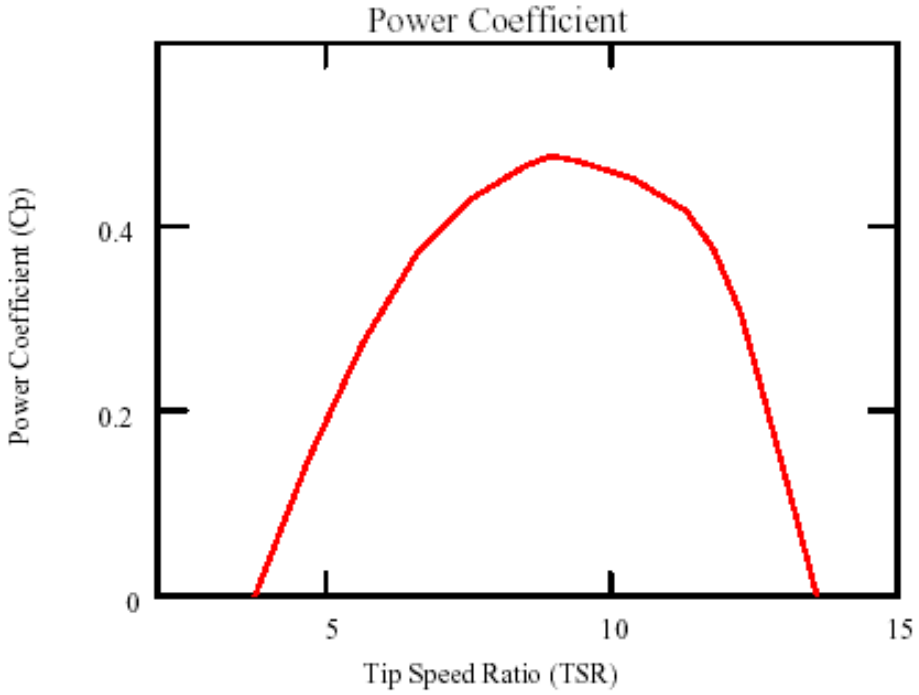
- Fix bladed rotor
- TipSpeedRatio:

$$v_{\text{blade edge}} / v_{\text{air}}$$

- 100 %? no



Different rotors and blades

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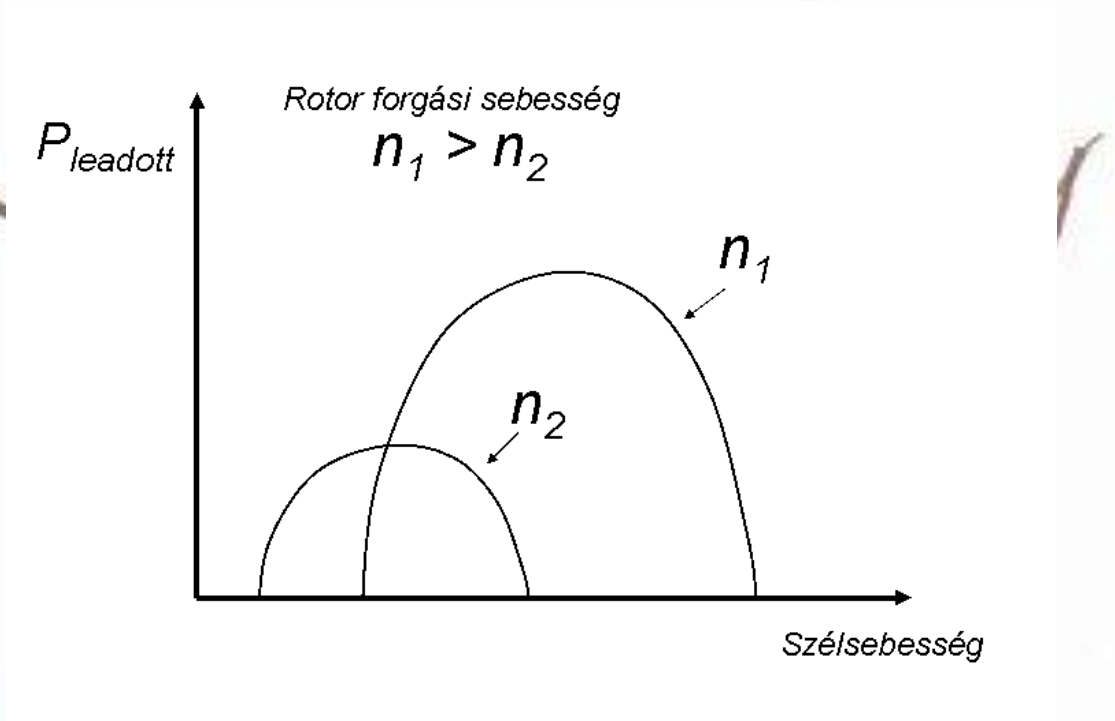
- P vs wind speed
- Different rpm



Practical characteristics of wind turbine with control

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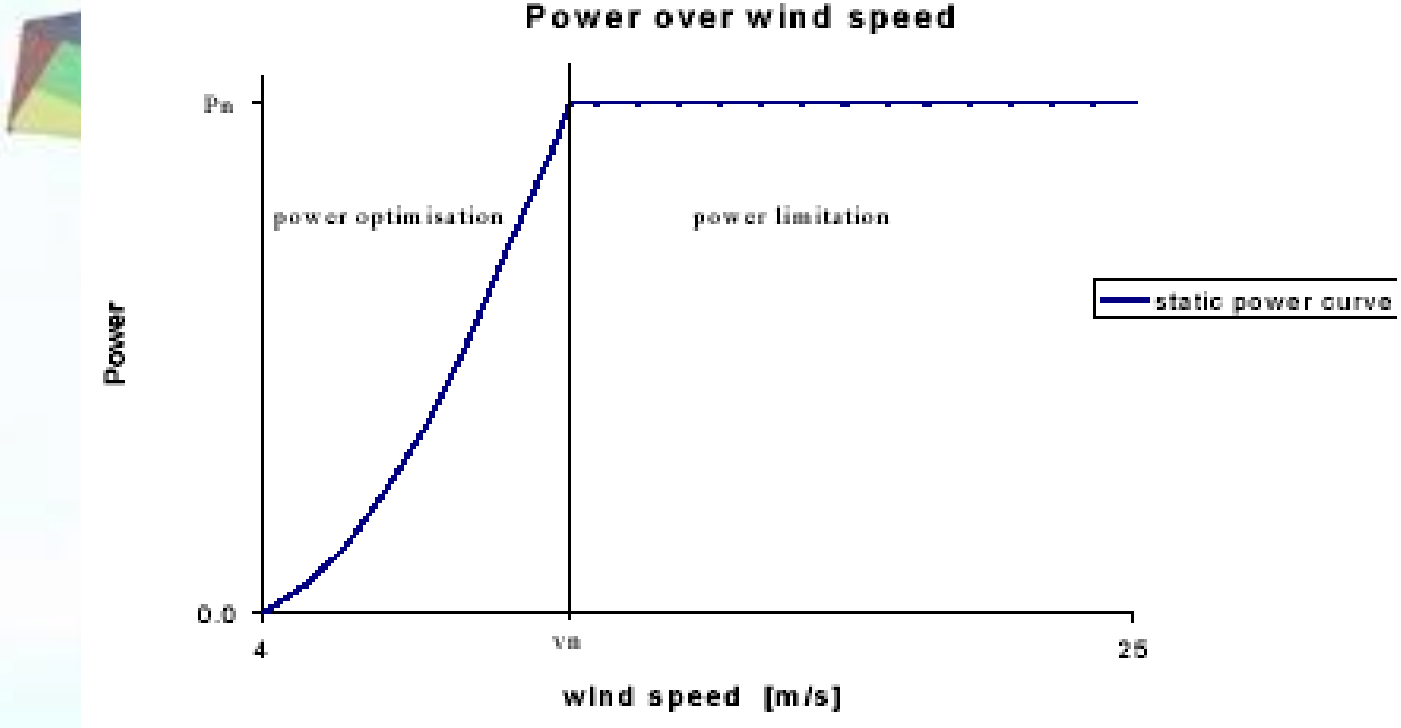
Electronic control of

- Rotor speed
- Pitch



Factory characteristics

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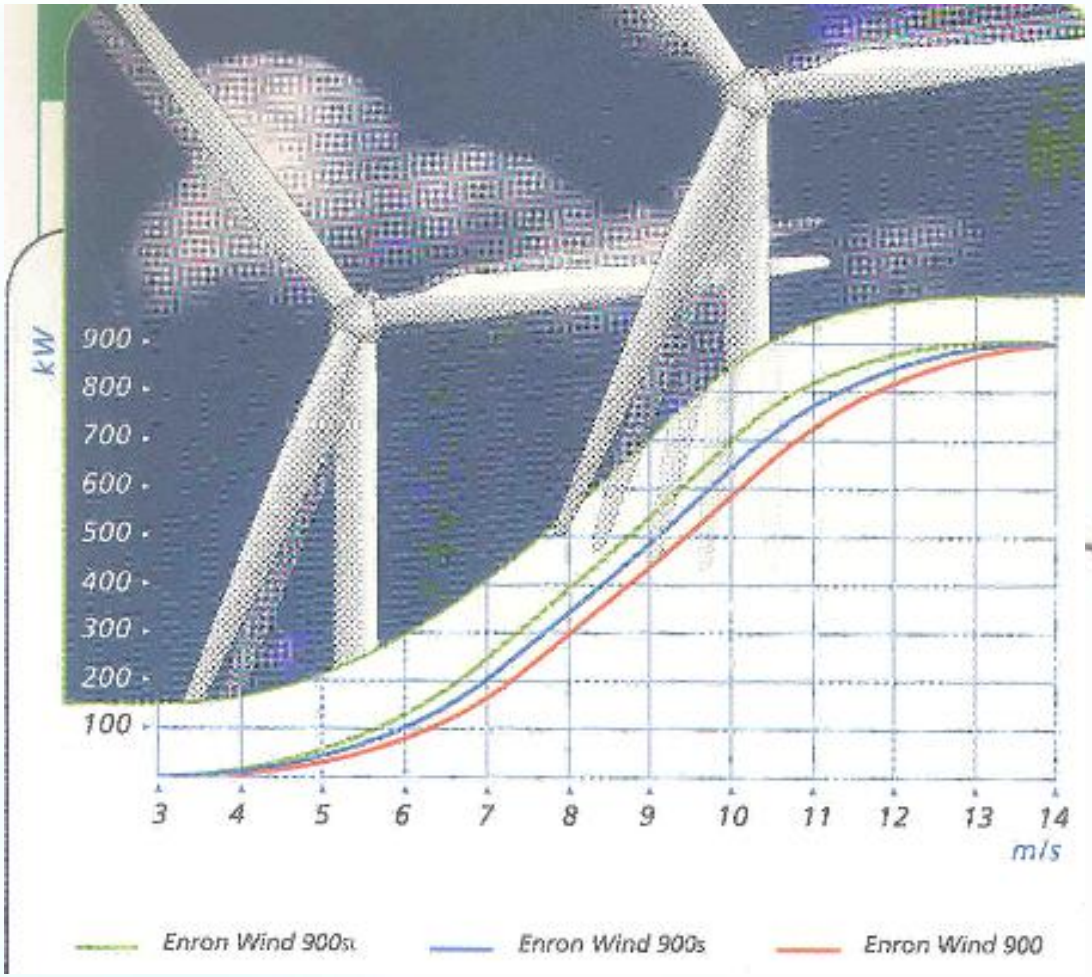
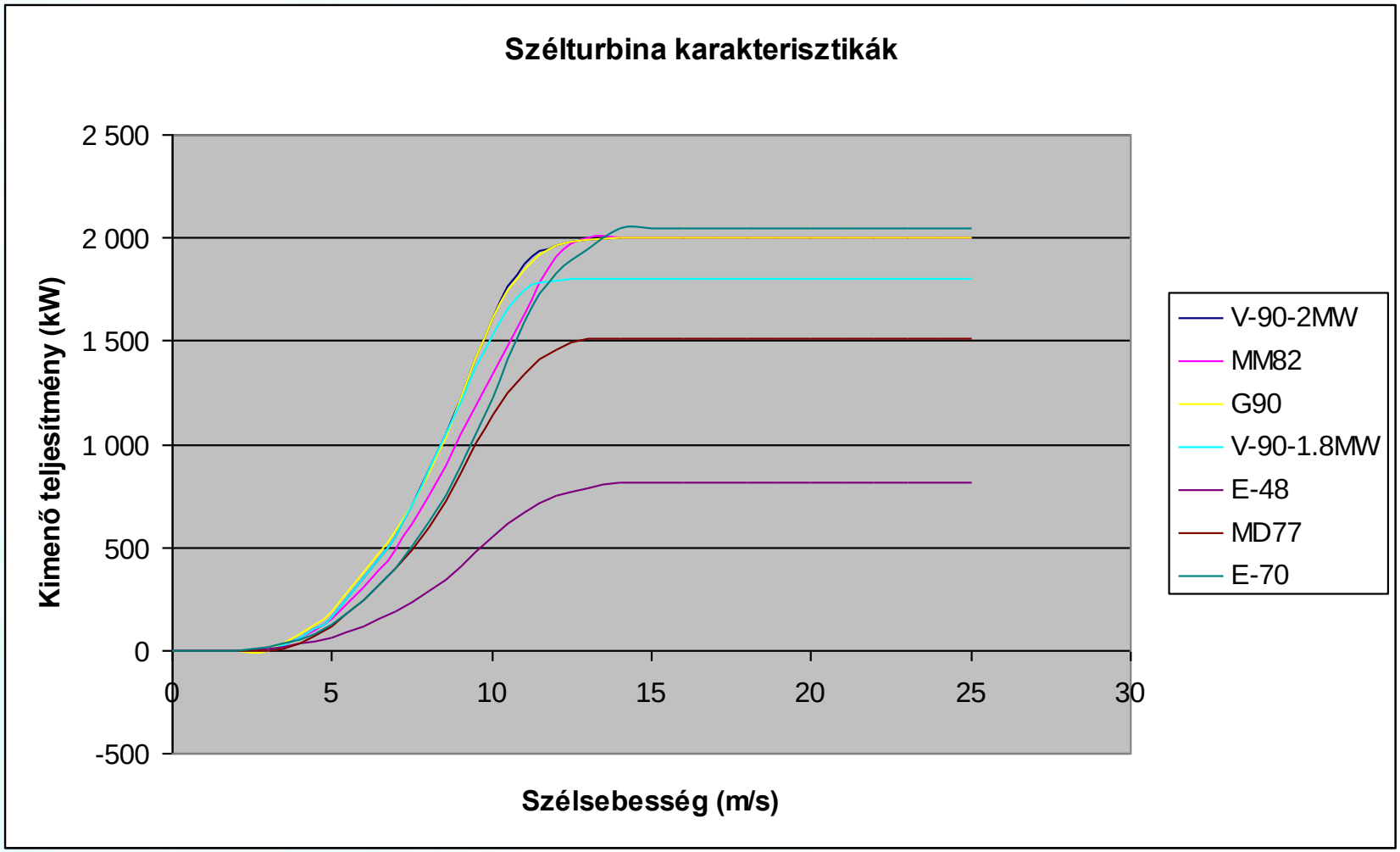


Typical characteristics



Performance measurements

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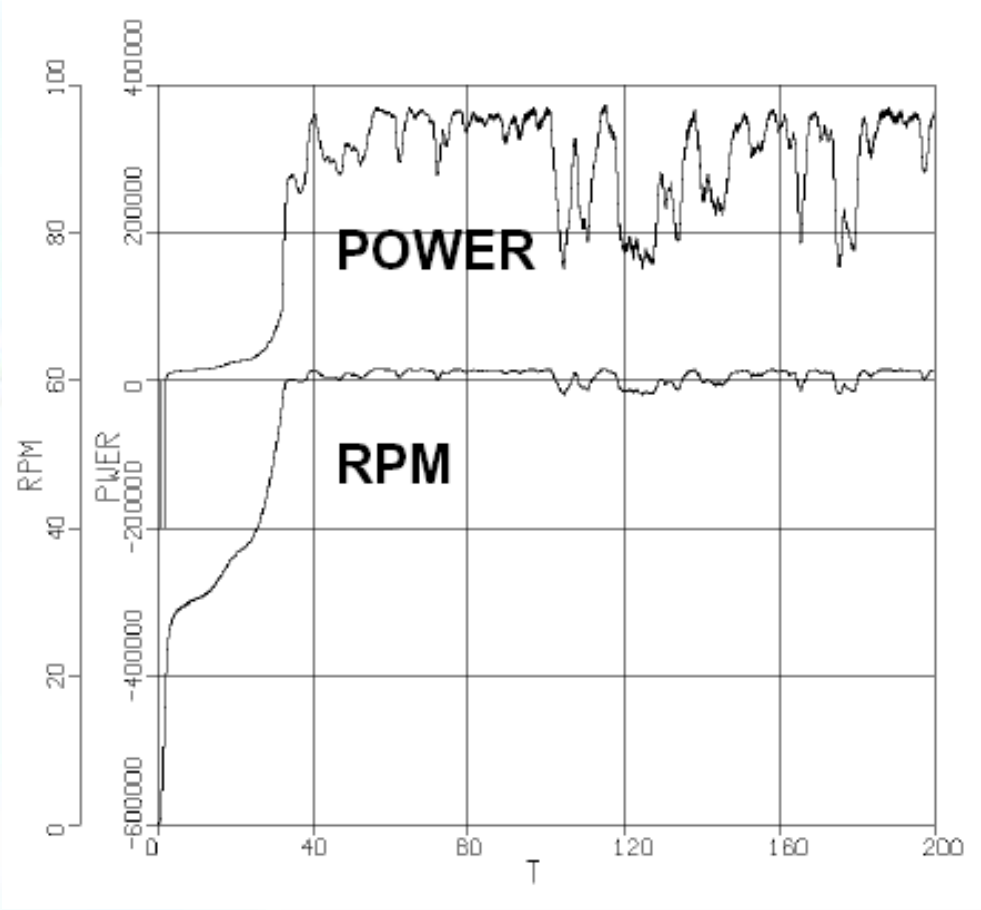

Dynamic simulation

Simulation logic

- Basic questions: „What happened if…”
- No yearly averages but
- Real wind measurements +
- Defined wind park locations +
- Wind turbine characteristics
- Result: MW curve during a long period (a year)

Investigated places, parks

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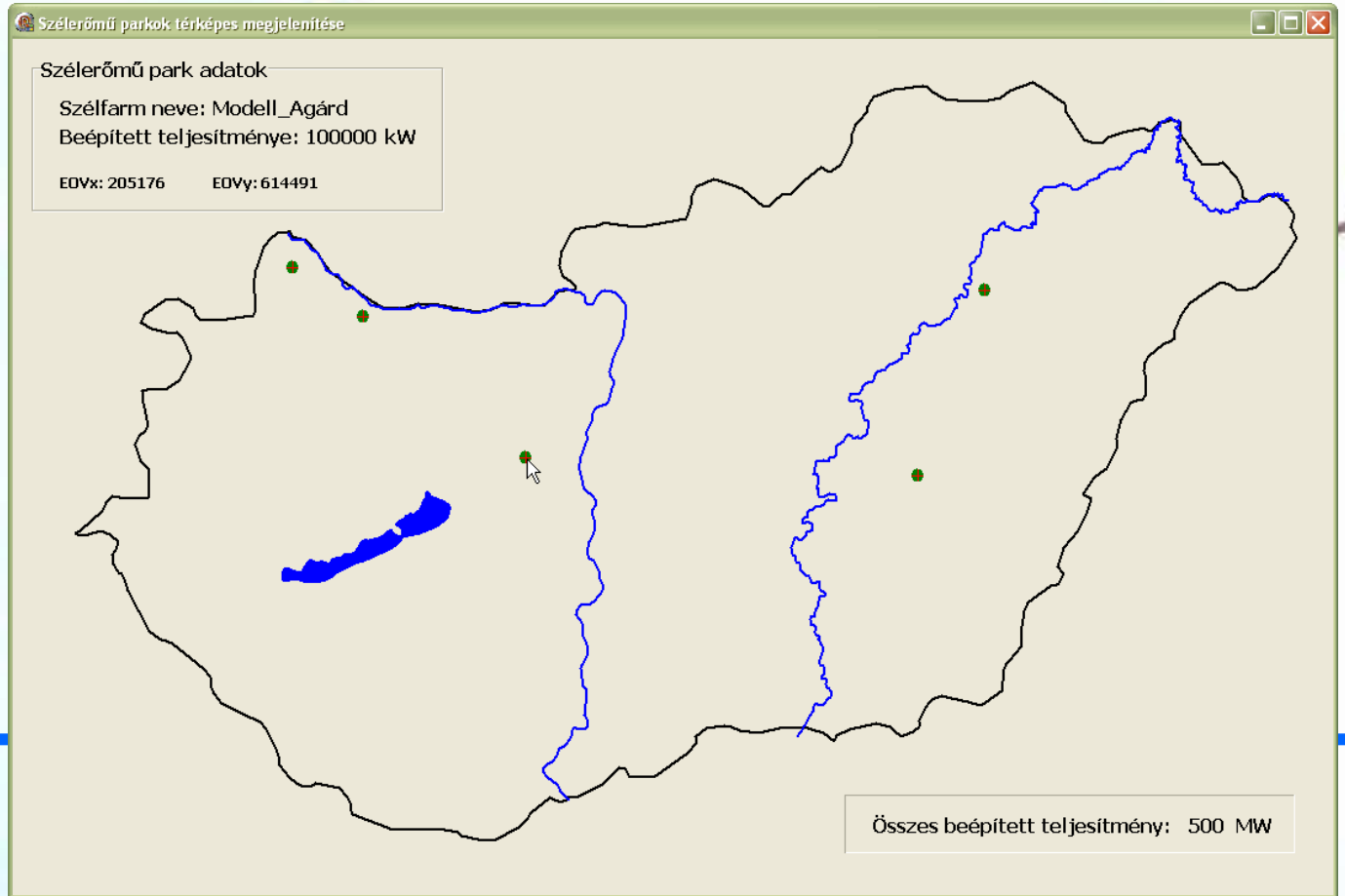
Szélfarm neve	EOVx	EOVy	Beép.telj.	Gépszám	Géptípus	Magasság	Alfa	Közeli referenciapont	Szélseb.sz.
Modell_Agárd	205176	614491	100000	50	V90-2MW	105	0,3	Agárd	2,0247
Modell_Folyás	274983	806657	100000	50	V90-2MW	105	0,3	Folyás	2,0247
Modell_Győr	263793	546556	100000	50	V90-2MW	105	0,3	Győr	2,0247
Modell_Moson	284407	517000	100000	50	V90-2MW	105	0,3	Moson	1,7267
Modell_Túrkeve	197566	778361	100000	50	V90-2MW	105	0,3	Túrkeve	2,0247



Frequency of the output changes

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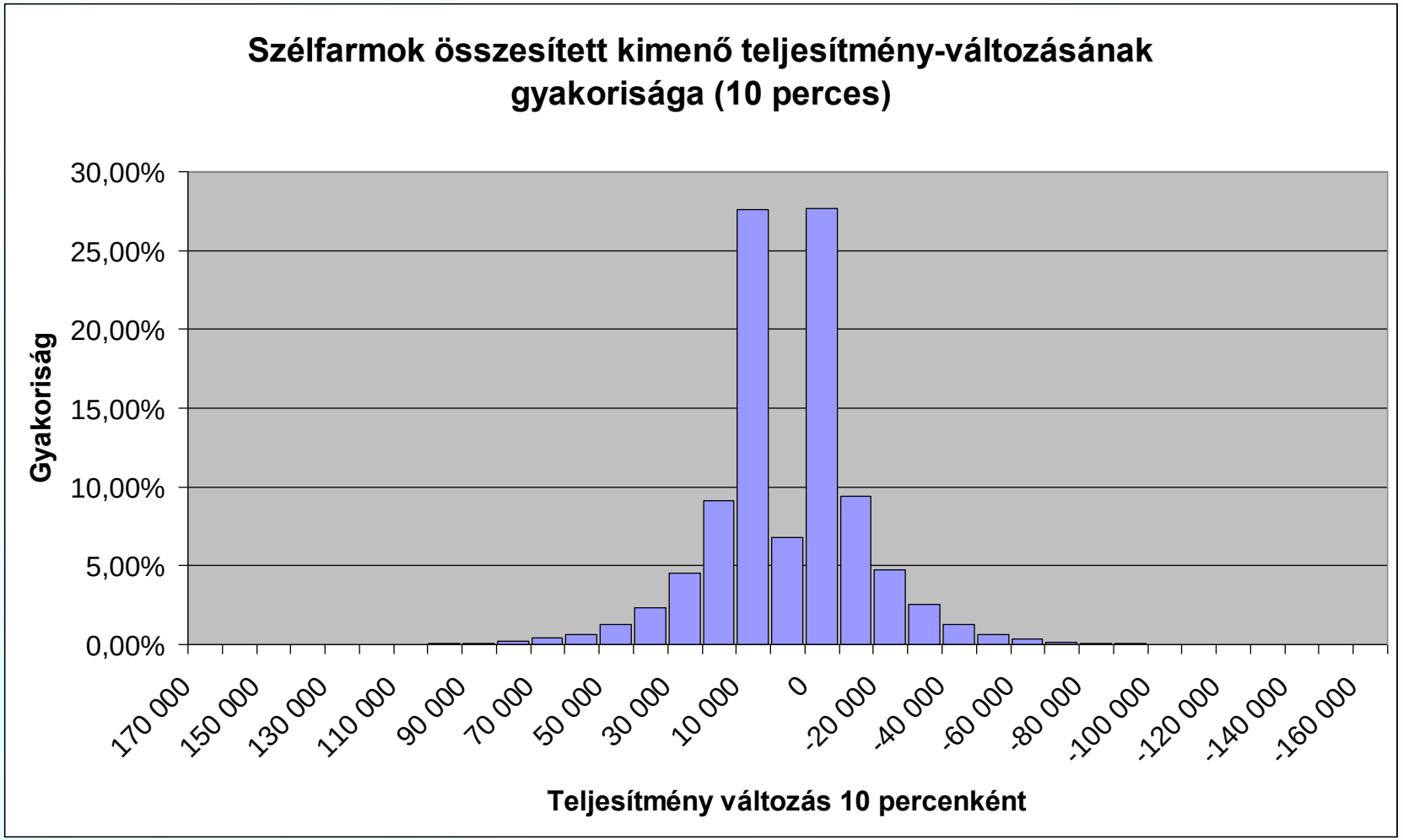
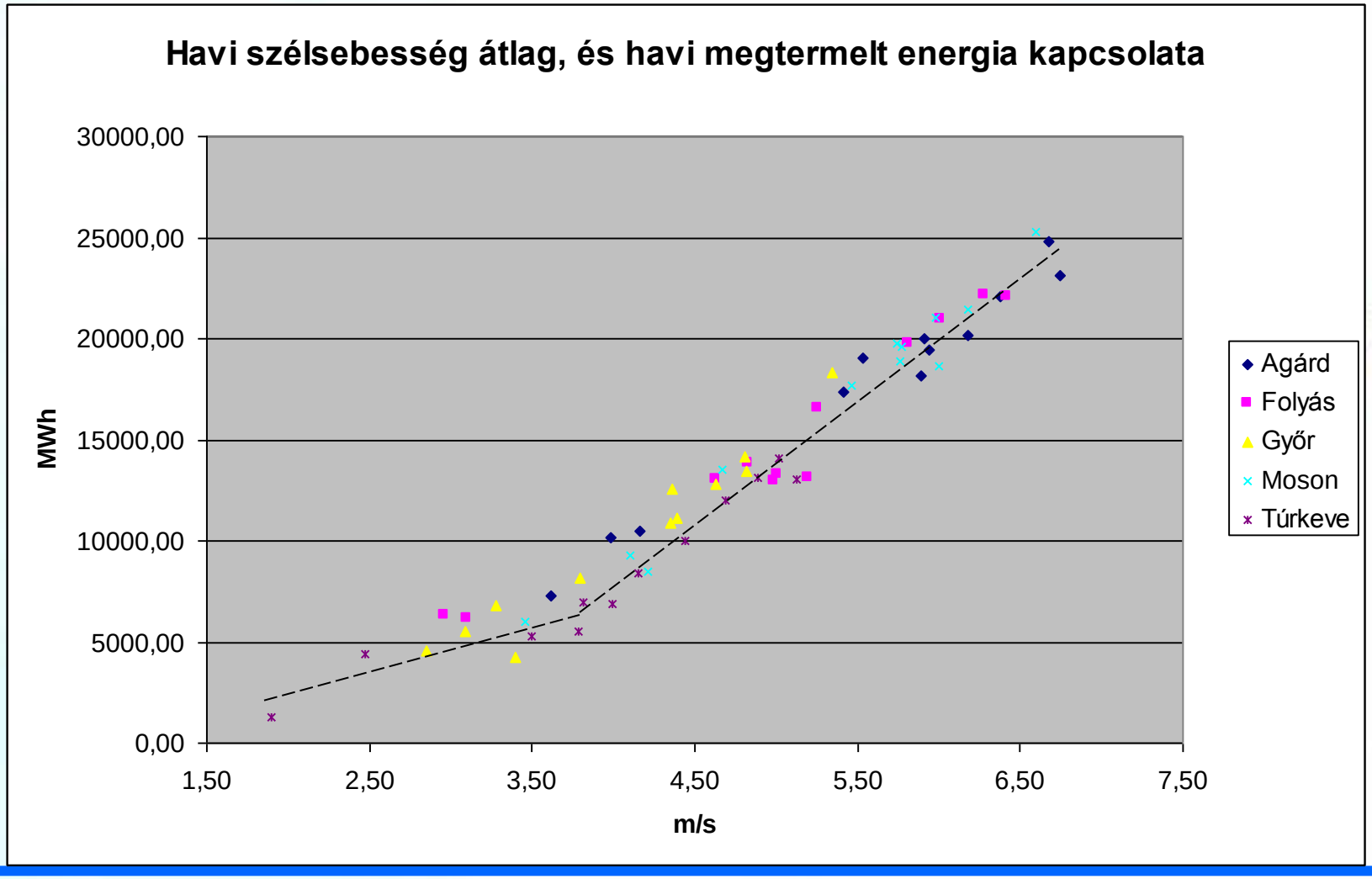
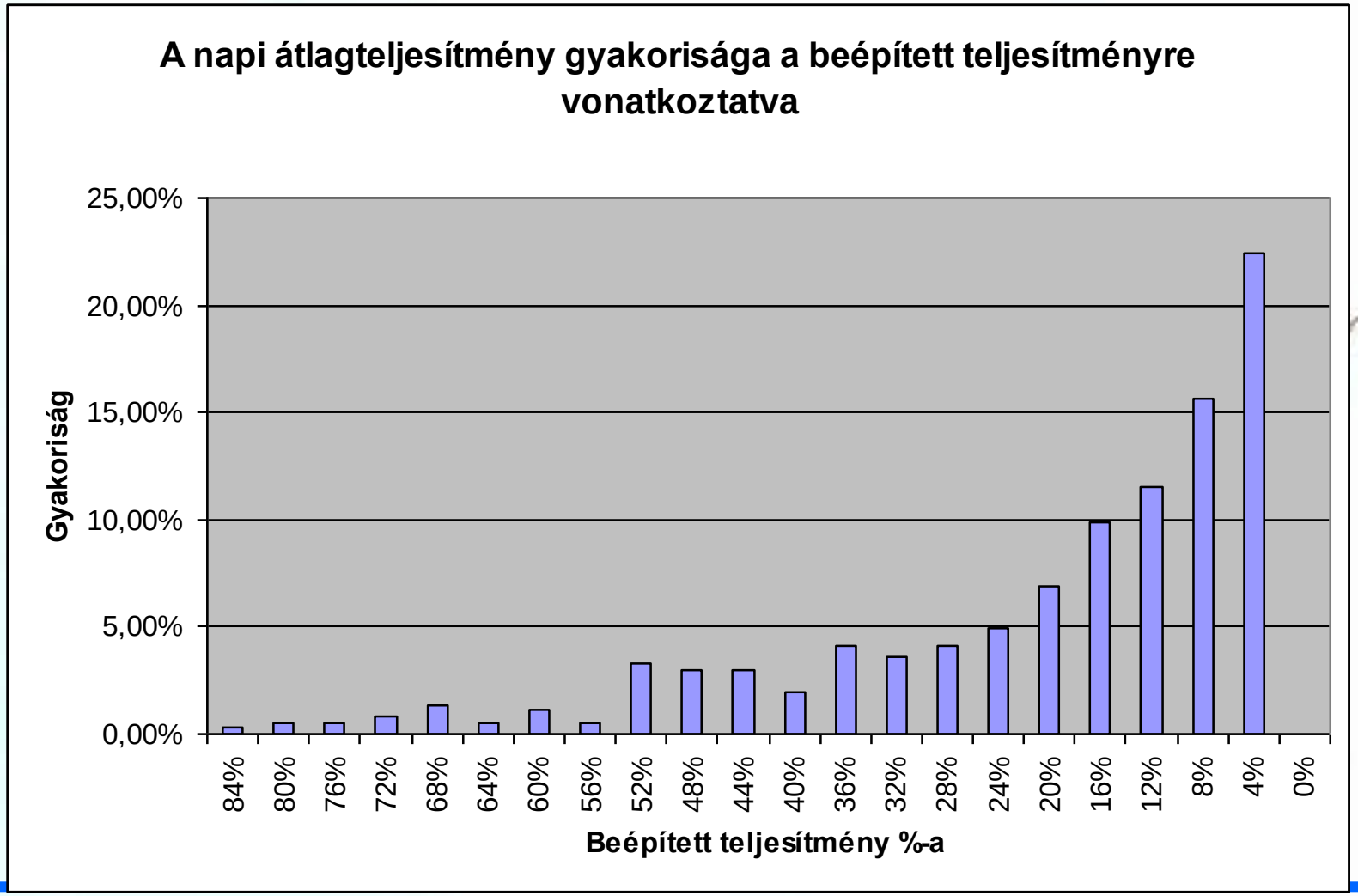


Average wind speed vs monthly production



Daily energy production vs built in capacity



Monthly energy production

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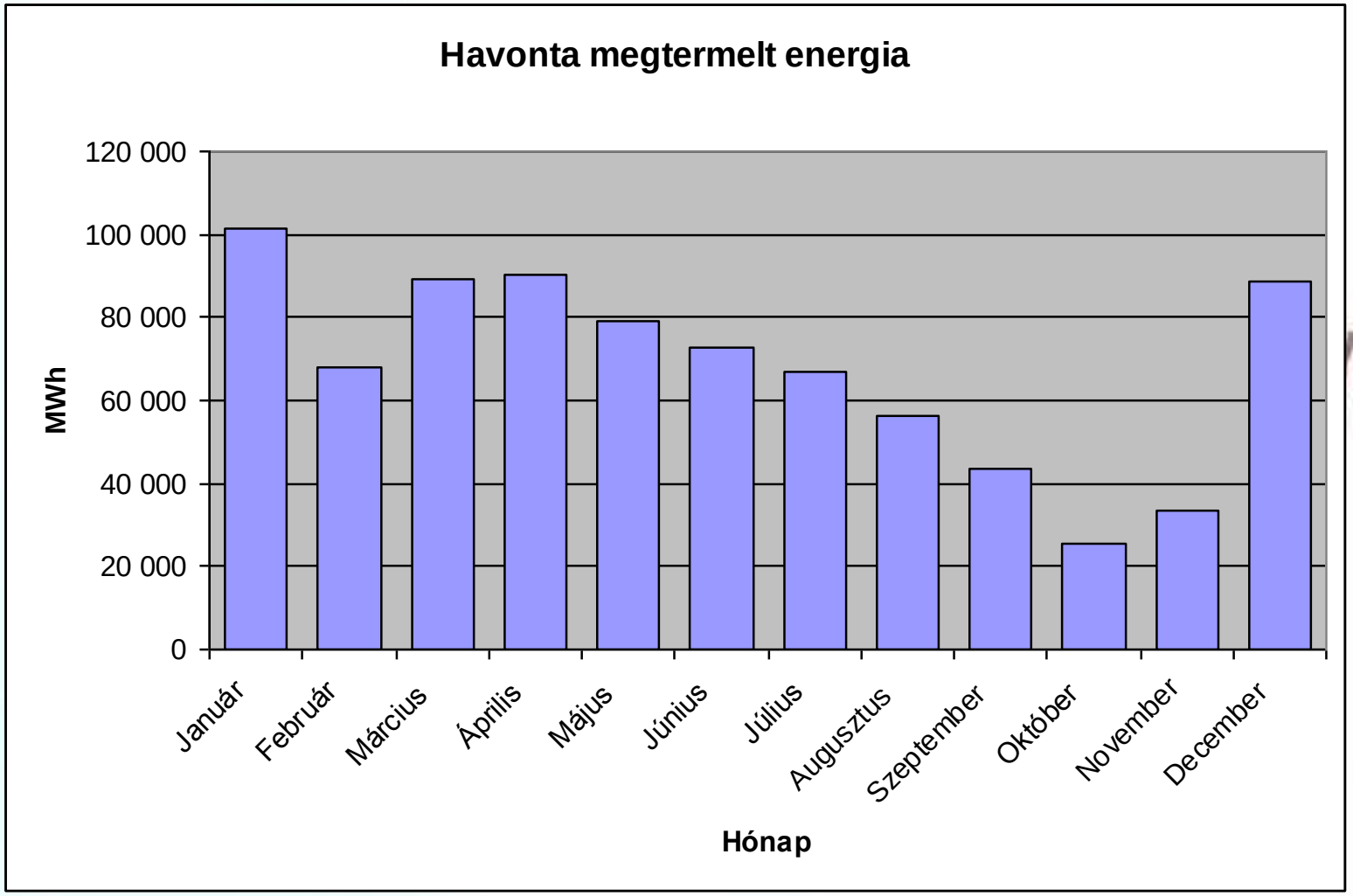

Small wind

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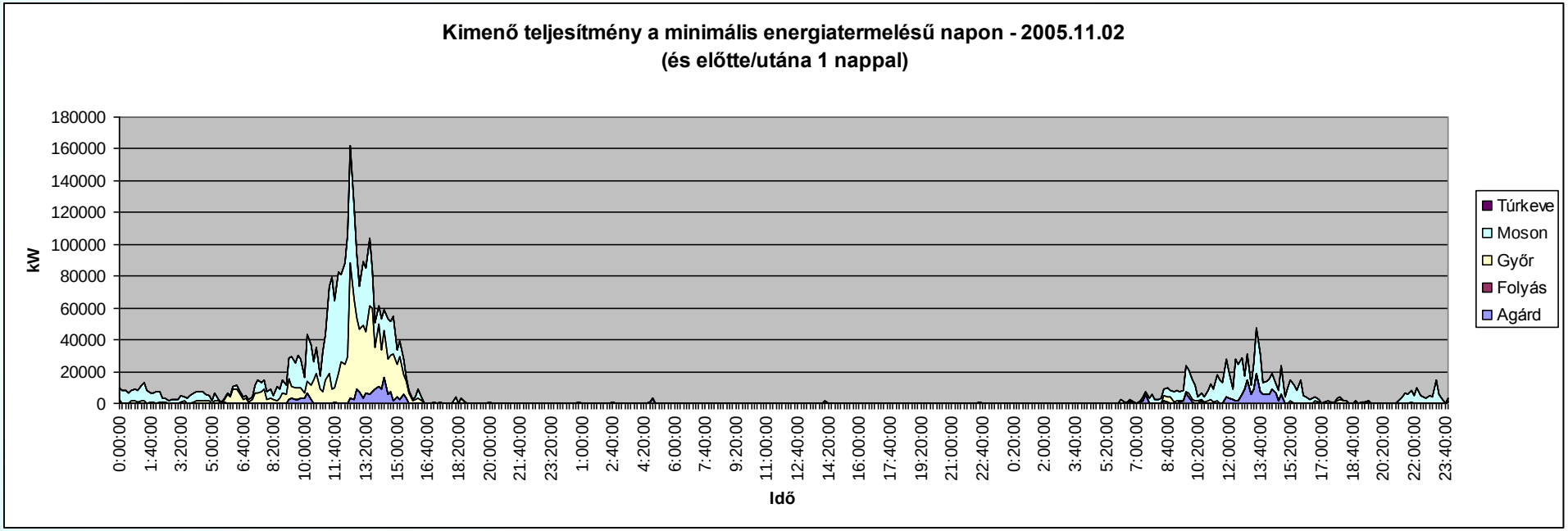

Large wind

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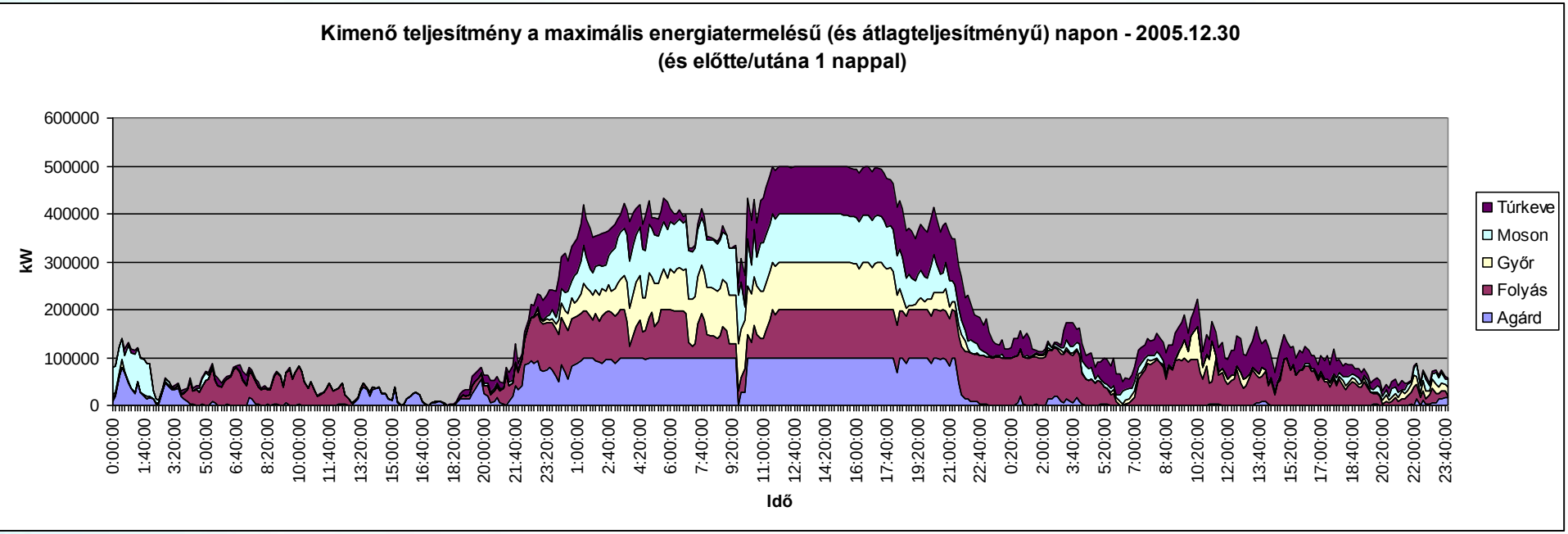

Meteorological front in and out

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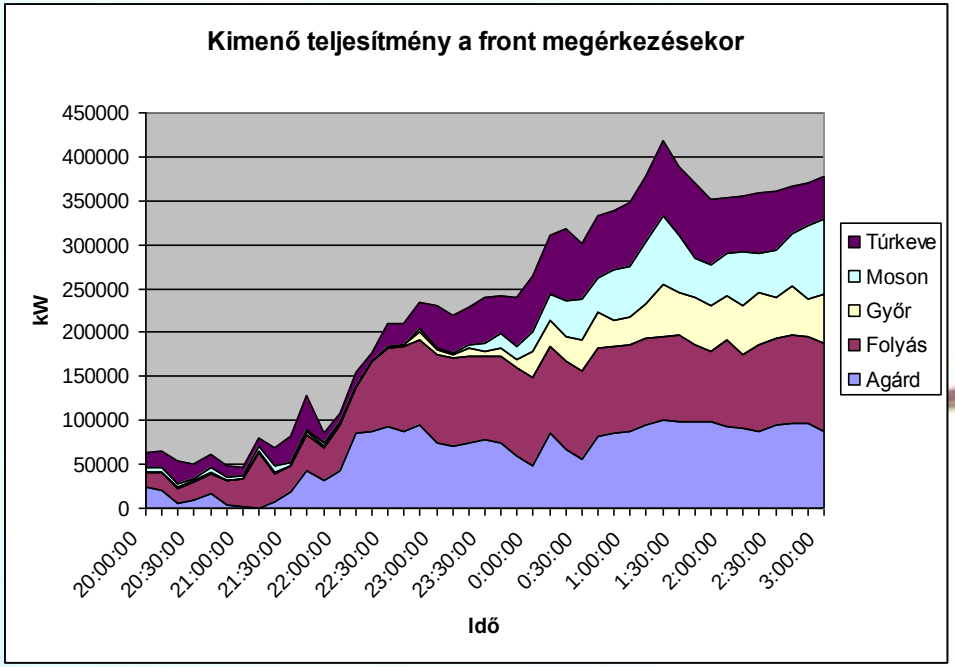

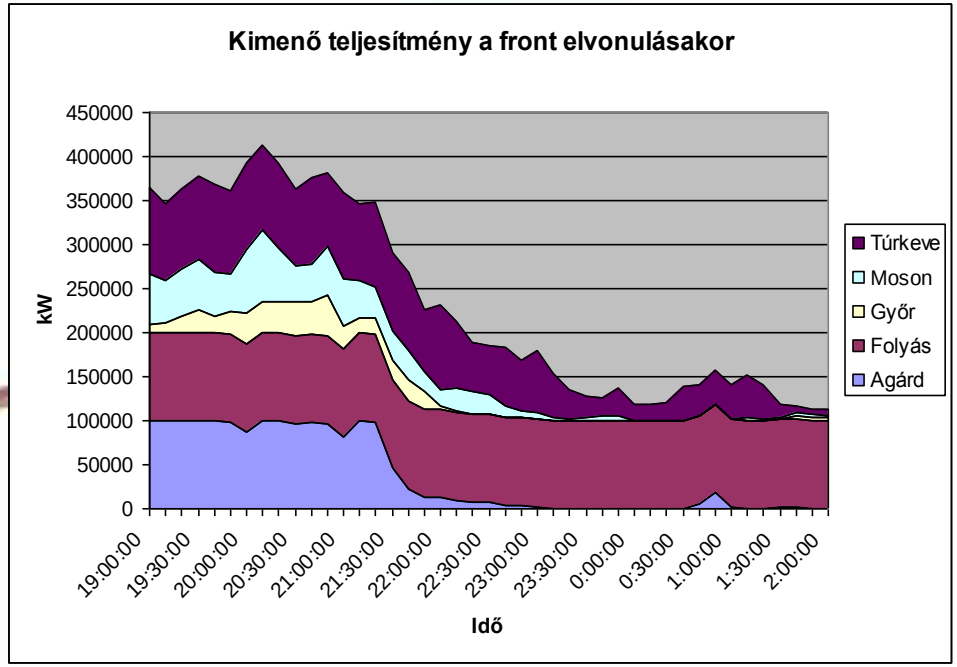

The „problematic” days

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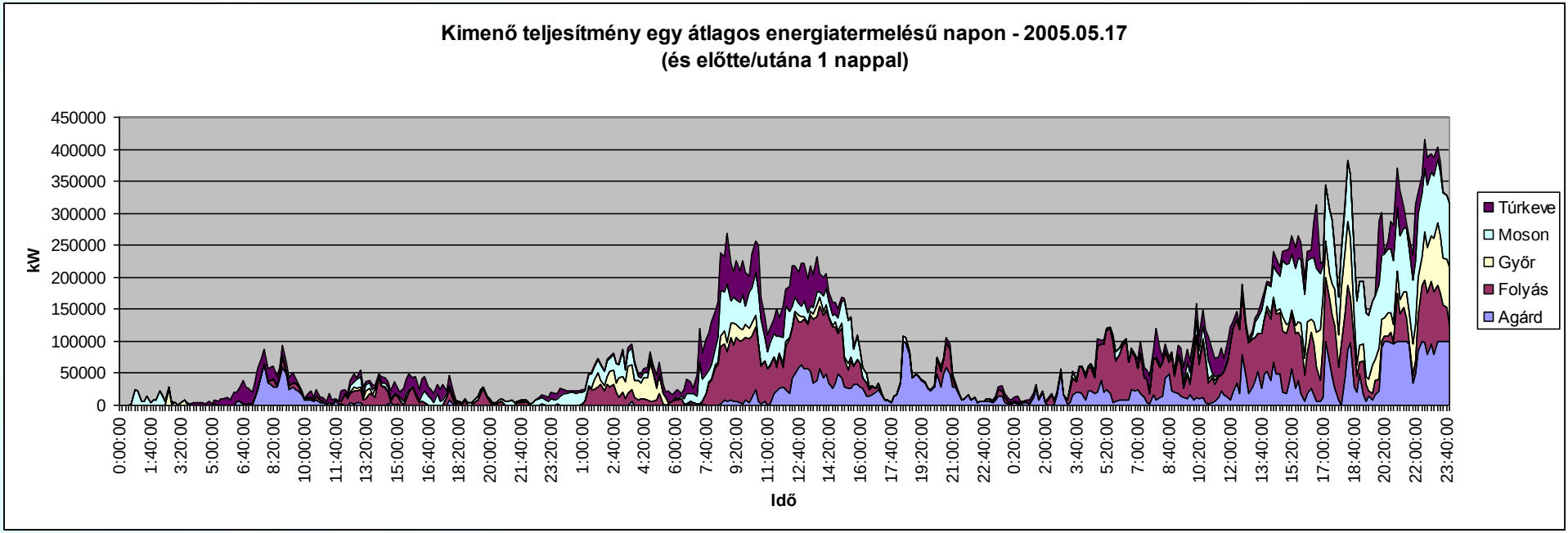

Correlation analysis of wind measurements

The problem

- Wind production forecast =

  wind forecast + turbine caharactereistics

- There is no exact wind forecast for the wind turbine sites
- The forecast is crucial for the integration large wind parks into the network
- The question: Can we forecast the generated energy based on remote wind forecast?

The real task

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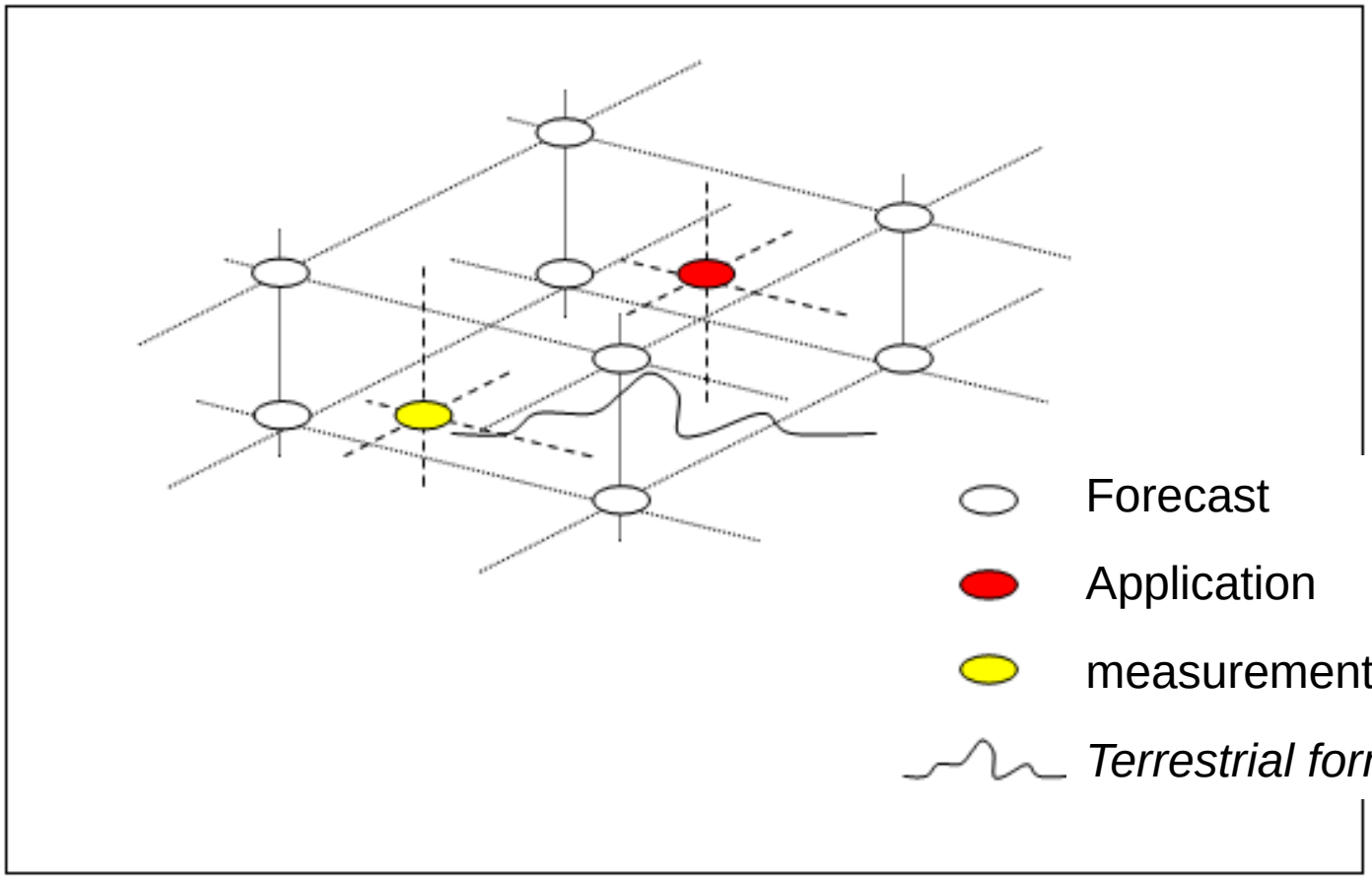
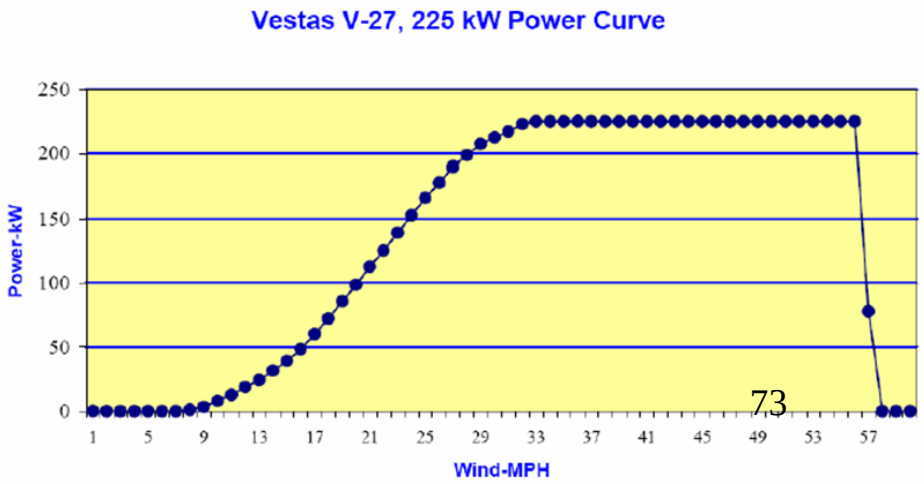
- Not in that place
- Not in that time
- Not correct wind forecast

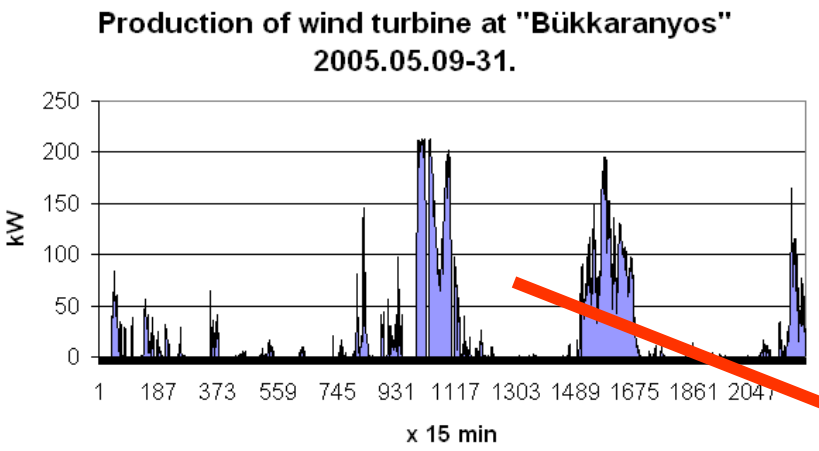


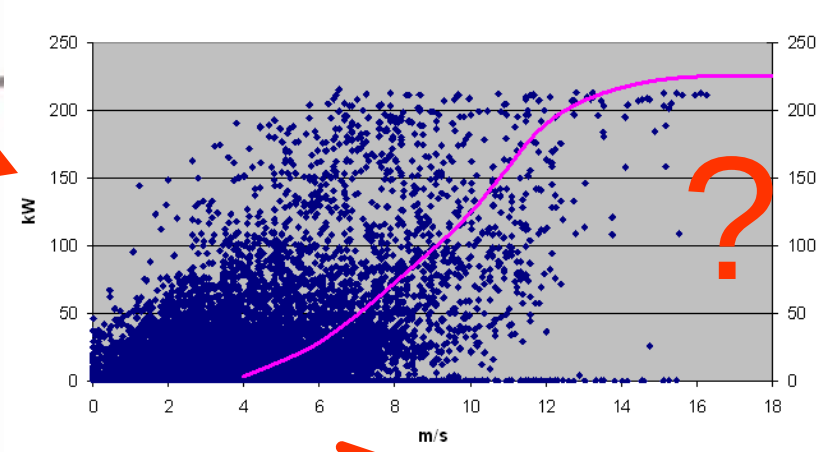
The factory characteristics

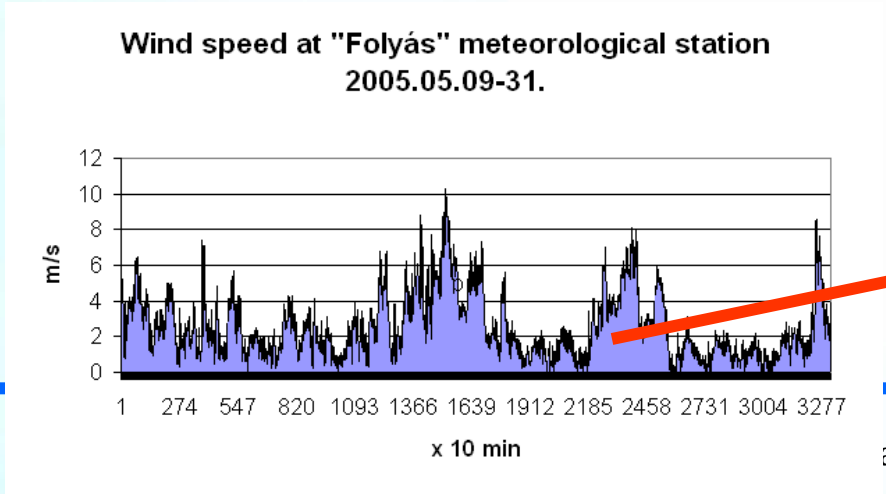
- In the project we investigate a V-27 turbine at “Bükkaranyos” and wind measurement ant “Folyás” meteorological station.
- The figure shows a typical characteristics of wind turbines (V27). This curve is measured in stationary mode, it does not contain the effect of local turbulences, direction changes and wind speed differences between the upper and lower part of the (spinning) rotor measurements.



Characteristics based on pure measurements







Correlation?

The causes of the lack of correlation are

- The *distance* between the wind turbine and wind measurement
- The local wind turbulences that create difference in the wind blow at the two measurement points.

Other causes: turbulence

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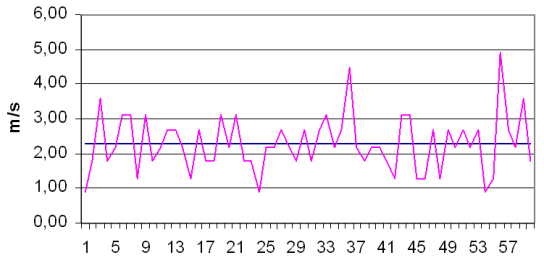
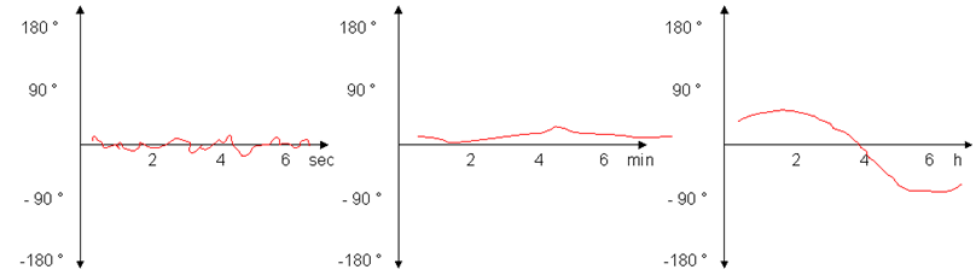
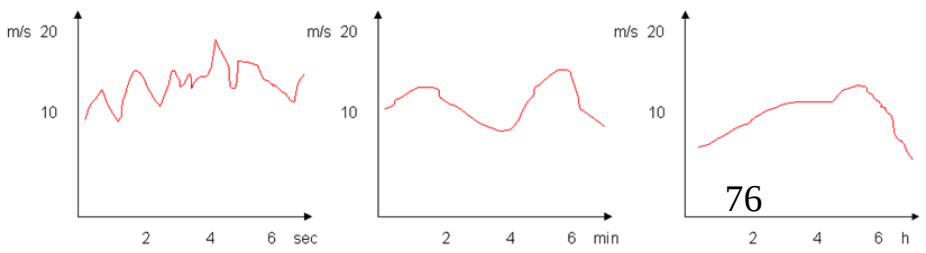
- The local wind turbulences that create difference in the wind blow at the two measurement points.
- fast (1-6 sec), the medium (1-6 min) and the slow (1-6 hour) changes.
- The fast and medium wind speed and direction changes are not handled (followed) by the turbine, it causes *deviances*.
- Turbine dynamics and measurement *errors*, etc.
  - Wind speed changes
  - Wind direction changes
  - Wind speed changes measurement on minute scale

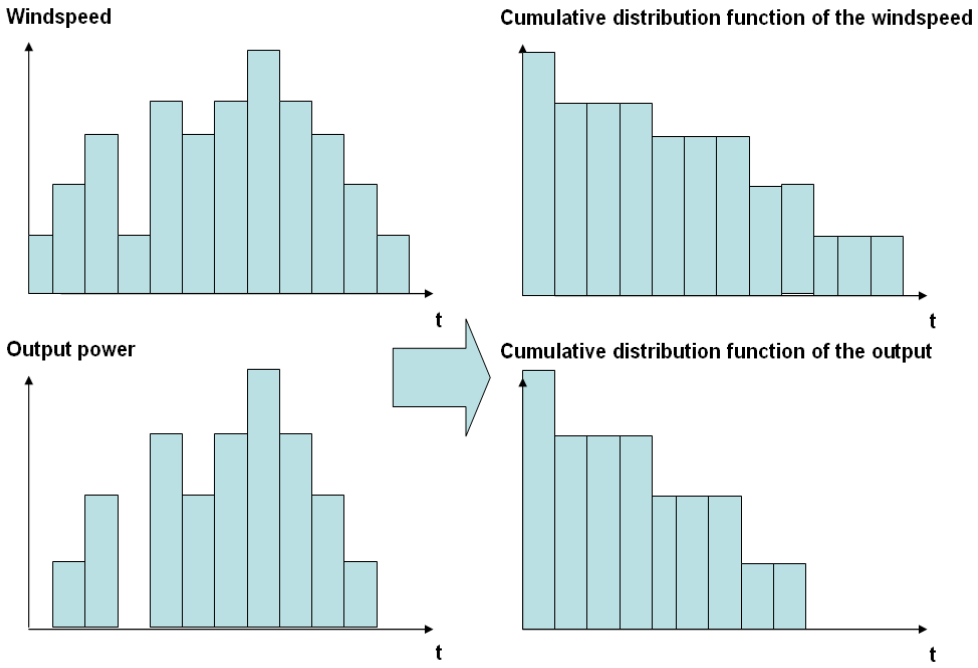


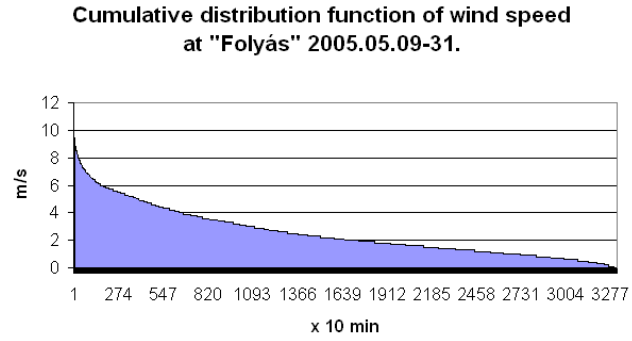


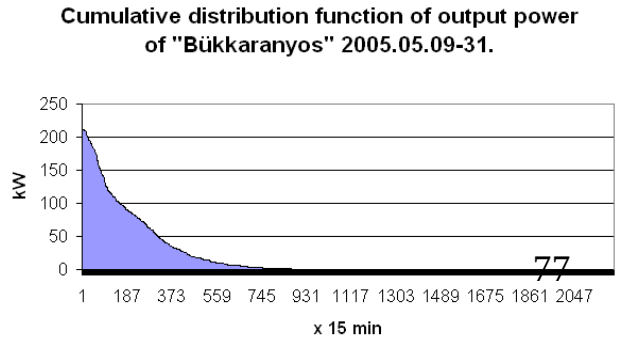


Distributional reorganization: a functional transformation

An ideal wind speed and power output measurement at the same tower should give the factory characteristics of the wind turbine, the two measurements correlate on the factory curve. If we prepare the cumulative distribution function of both measurements, the previous correlation is still valid and we get the same curve.

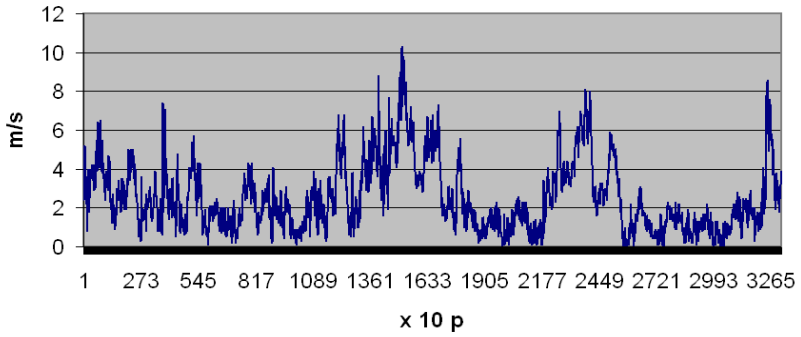




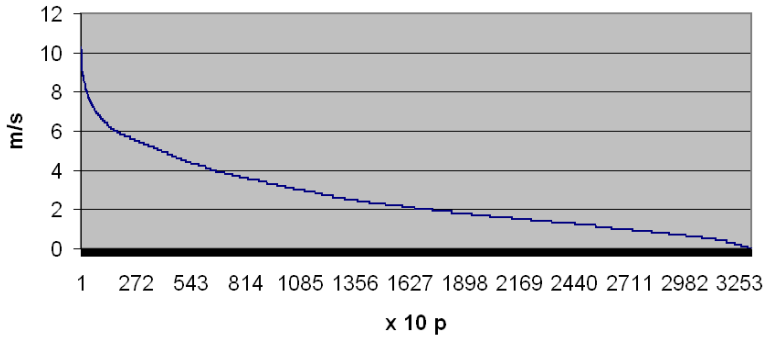


Back to the measurements (Bükkaranyos – Folyás: 33km)

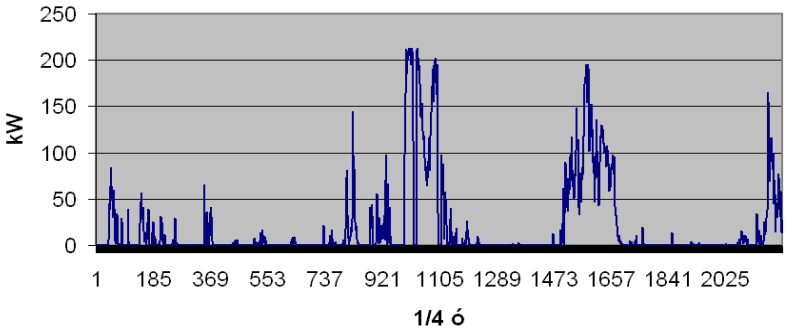
Szélsebesség, Folyás 2005.05.09-31.



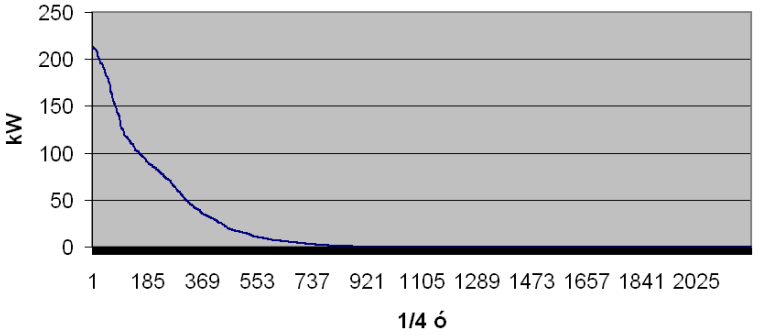
Szélsebesség eloszlás, Folyás 2005.05.09-31.



Bükaranyos termelés 2005.05.09-31.



Bükkaranyos teljesítmény eloszlás 2005.05.09-31.



Characteristics matching

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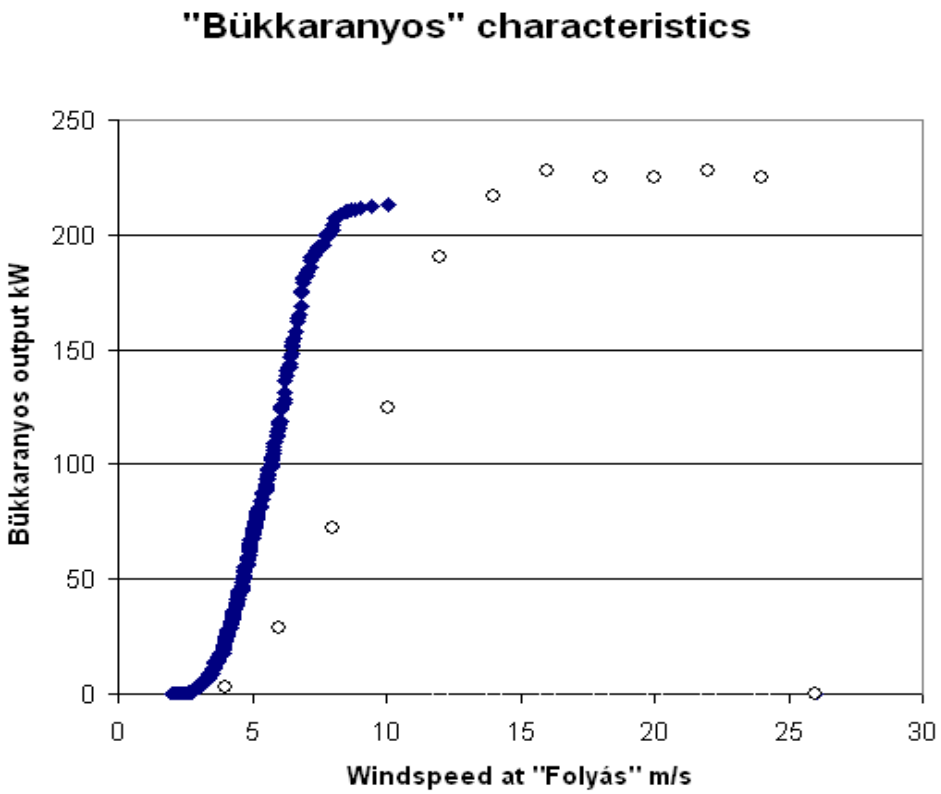
Based on the above mentioned, the locally differently running curve is substituted by a globally similarly cumulated distribution function. We investigate not the specific synchronized moments but the same period, so we integrate the power into generated energy. This is an energy based characteristics retrieval. Figure shows characteristics similar to the factory characteristics (marked by dots).



Meaurement distances

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Name of wind measurement place	*Distance of the wind turbine "Bükkaranyos"*
Folyás	33 km
Agárd	187 km
Túrkeve	98 km
Mosonmagyaróvár	263 km
Győr	238 km

Wind power generation forecast

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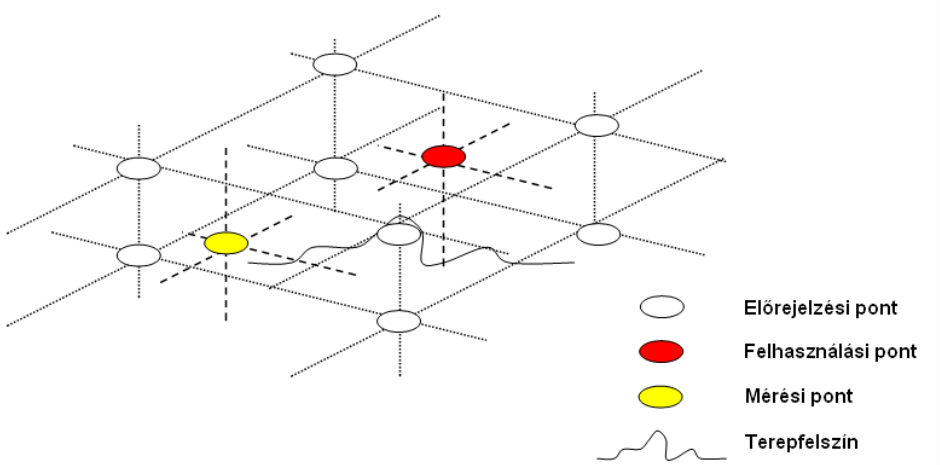
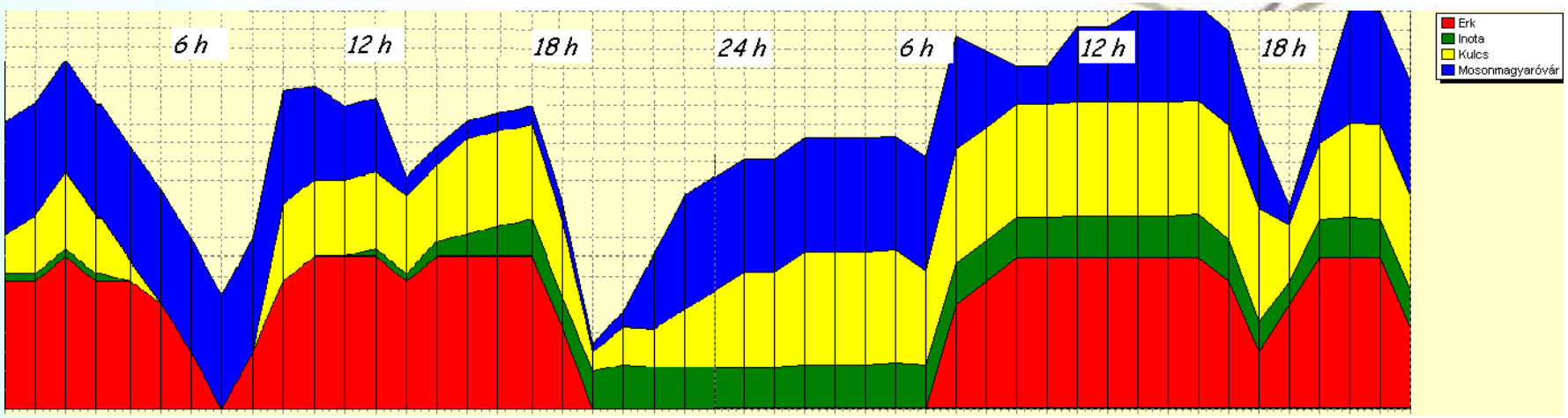
See WinDemo!





Wind power generation forecast

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Rough:

- Windspeed
- Characterеistic

Fine

- + temperature
- + pressure
- + humidity
- + direction

CORRELATION FACTOR!

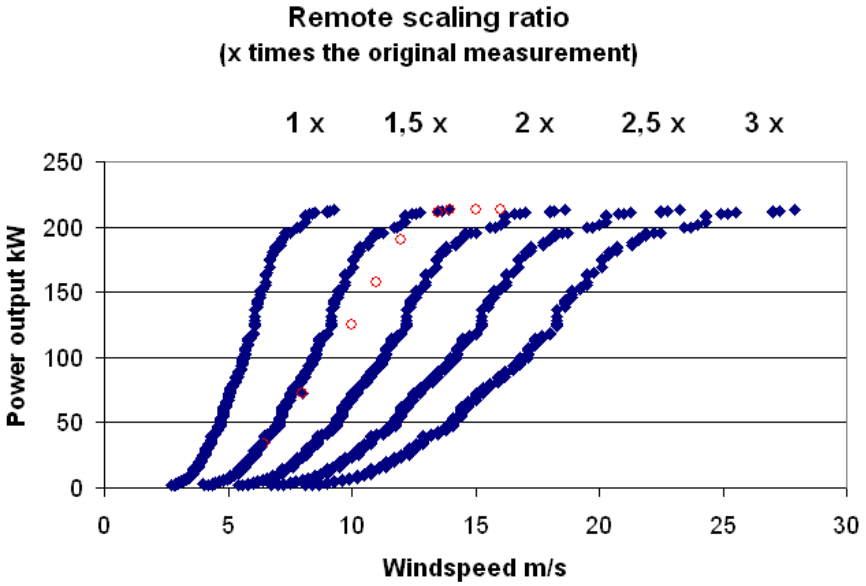
Upscaling

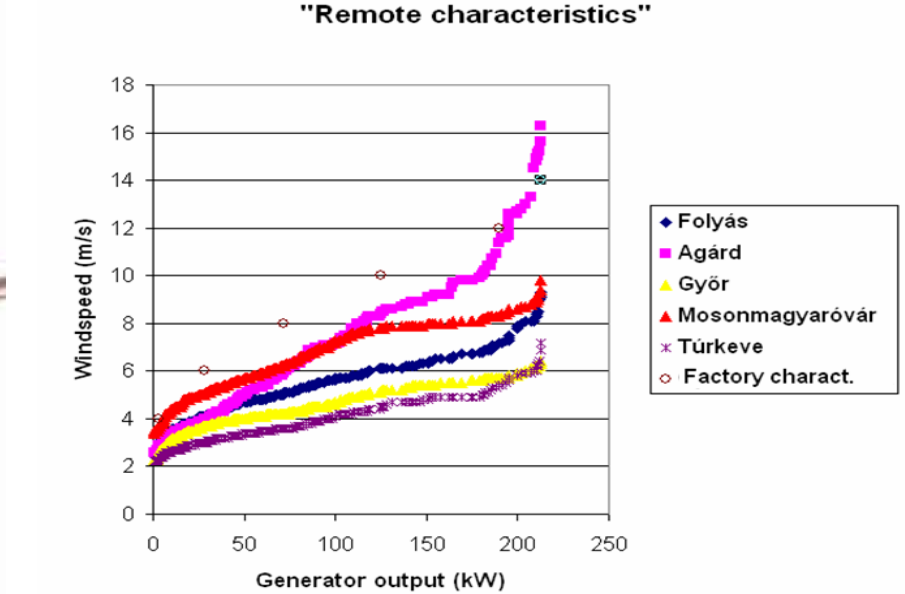
- The previously shown remote upscaling factor is defined by the energy production of a time period. Applying the Hellmann equation (1) for the same tower (height 33 m, measurements height 10 m), the exponent is 0,445, that is a good experimental result.

$$u_z = u_m \left(\frac{z}{z_m} \right)^a \quad [\mathrm{m\,s^{-1}}]$$

$$1{,}7 = (33/10)^{0{,}445}$$

Remote scaling





Conclusion

- It is not possible to retrieve the vendor given stationary winds speed–generation characteristics of the wind turbine based on the real-time measurements.
- The calculations above show that for real-time generation forecast purposes only close measurement/estimation points could be used.
- The wind forecasts work on worldwide global models, these are theoretically not capable of forecasting local turbulences – which cause the 0,5 - 5 min deviations in the power output.
- In spite of this fact, based on further measurements quite good energy production estimations can be done. We used the cumulative distribution function to define the ratio between remote wind speed measurement and the possible local wind speed at the turbine.


Thanks for the attention!