On the worst case trajectories of microwave links above Belgium

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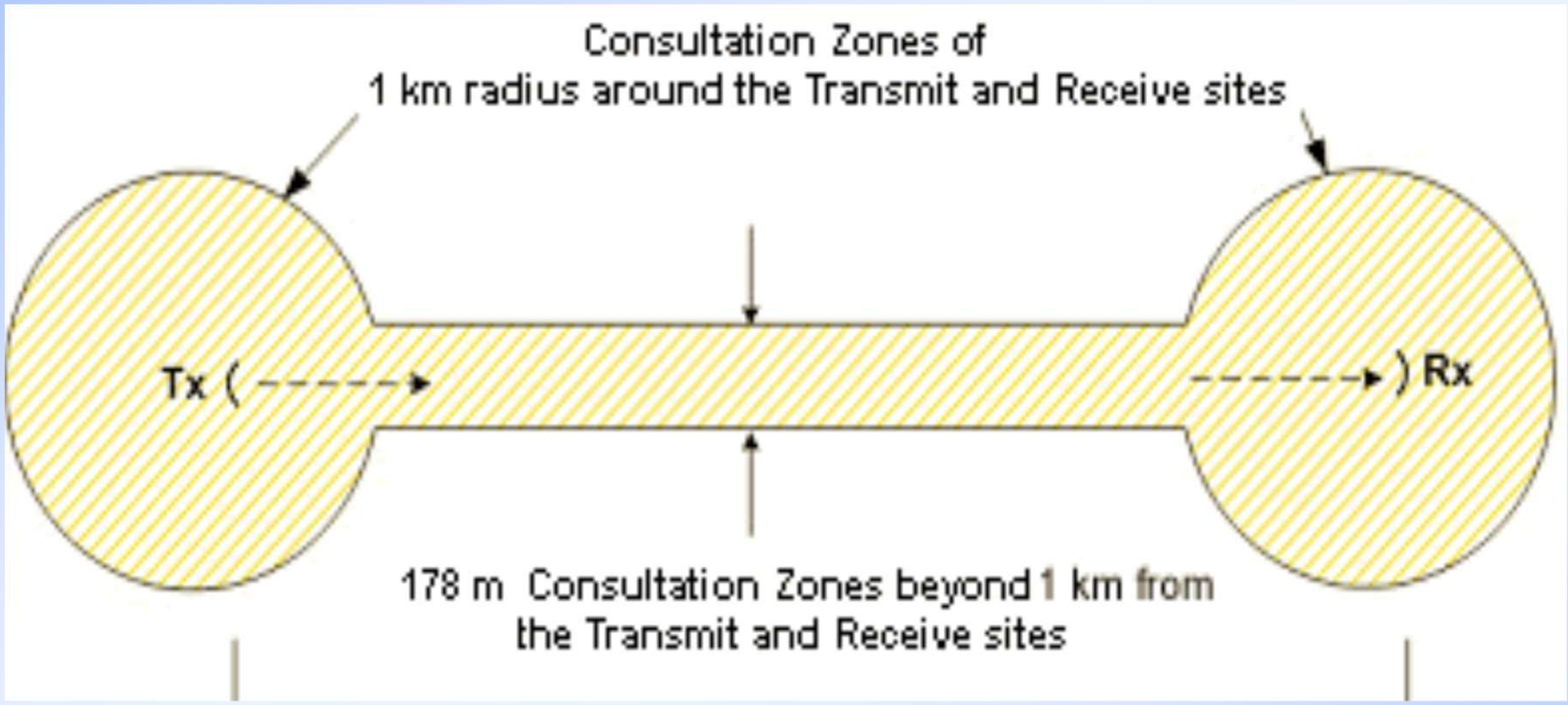
Outline

- Introduction: Consultation zones for microwave links
- Propagation theory & links in the presence of wind turbines
- Meteorological measurements
- Determination of extreme propagation conditions
- Application to microwave links in the presence of wind turbines in extreme propagation conditions
- Conclusions

Consultation zones for microwave links

- Horizontal projection free of obstacles



- Width is usually 3 times the width of the MAXIMAL first Fresnel ellipsoid.

Extent of the Fresnel ellipsoïds

- In practice, the fields are only slightly disturbed when the path difference is larger than $\lambda/2$. The locus of the points from the phase centers of the antennas is the first Fresnel ellipsoid.
- The general expression of the n^th order ellipsoid can be found analytically

$$b_n = \frac{\sqrt{A_n(A_n + 2d_1d_2)}}{d_1 + d_2 + n\lambda/2}$$

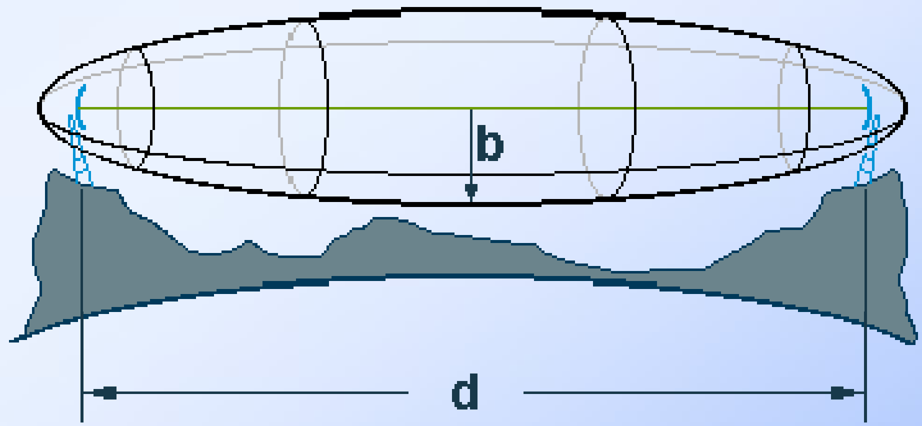
$$A_n = n\lambda(n\lambda/4 + d_1 + d_2)/2$$

- It is usually approximated by:

$$b_n = \sqrt{n\lambda d_1 d_2/(d_1 + d_2)} = \sqrt{n\lambda l}$$

- The maximum is in the middle

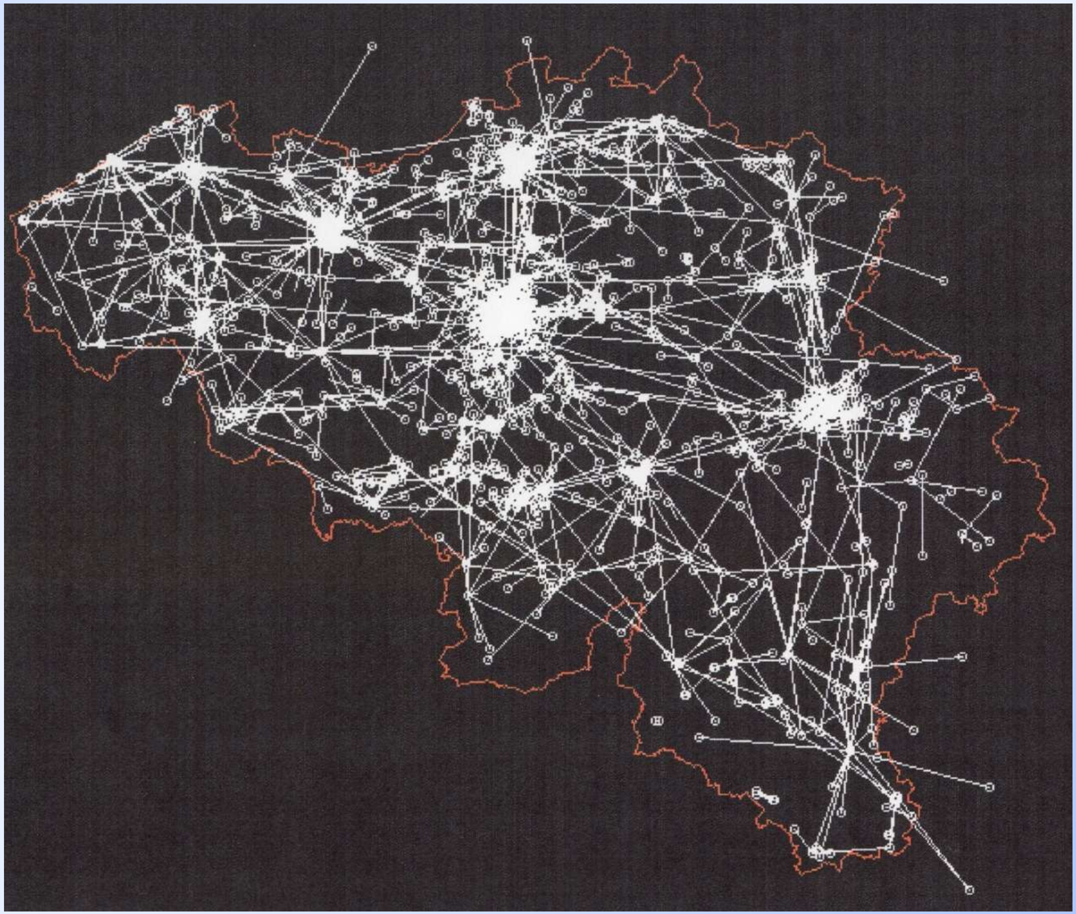
$$b_{n\max} = \frac{\sqrt{n\lambda(n\lambda/4 + d)}}{2}$$



$$d = d_1 + d_2$$

Consultation zones for microwave links

- Becomes difficult in a heavily populated country like Belgium (2004 map)

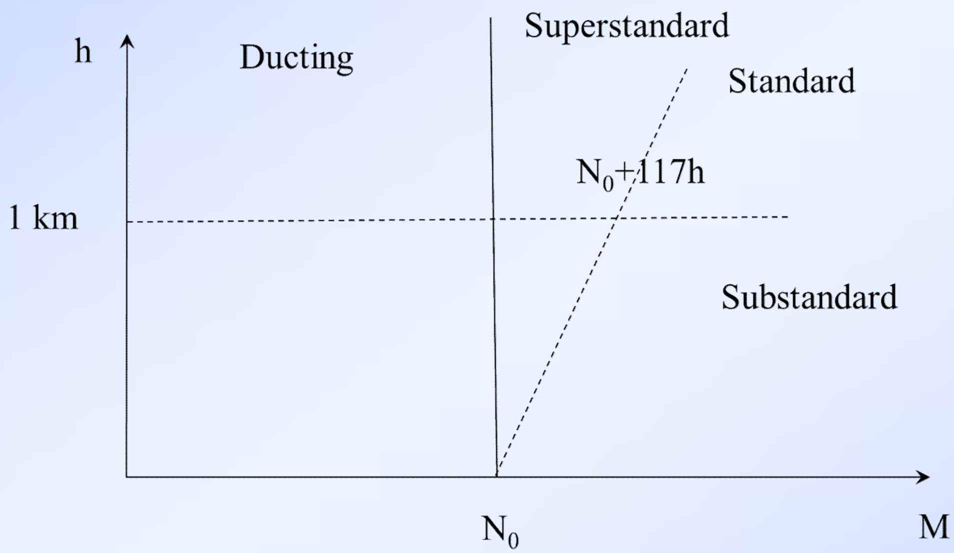


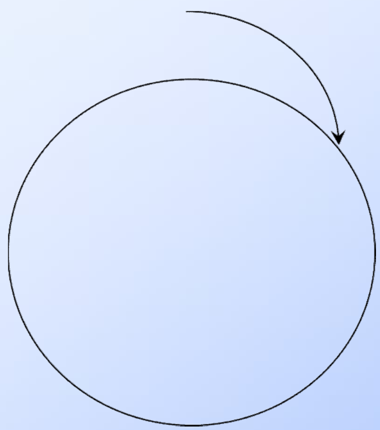
Propagation theory

- Path depends only on refraction index. This depends on meteorological data (ITU-R, recommendation P.453-11)

$$n = 1 + 77.6 * 10^{-6} / T \left[p - 0.072e + 4810e / T \right]$$

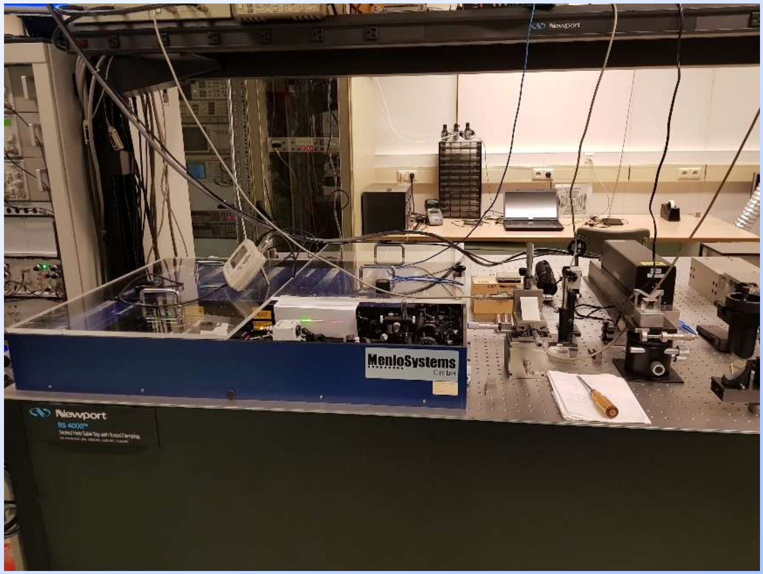
$$N = (n-1) * 1000000 \qquad M = N + 157h$$





Reftraction index also important in metrology

- The metre, symbol m, is the SI unit of length. It is defined by taking the fixed numerical value of the speed of light in vacuum *c* to be 299792458 when expressed in the unit $m \cdot s^{-1}$, where the second is defined in terms of the caesium frequency $\Delta\nu_{Cs}$
- Measurements in air (interferometer) should be corrected
- Picture = distance measuring equipment at the SMD (Belgian “Bureau of Standards”)



Engineering solution

- Use a fictitious straight line and bend the earth depending on propagation conditions with an equivalent earth radius

$$\frac{1}{R_{eq}} = \cos(\psi)\left(\frac{dn}{ndh} + \frac{1}{R_a + h}\right)$$

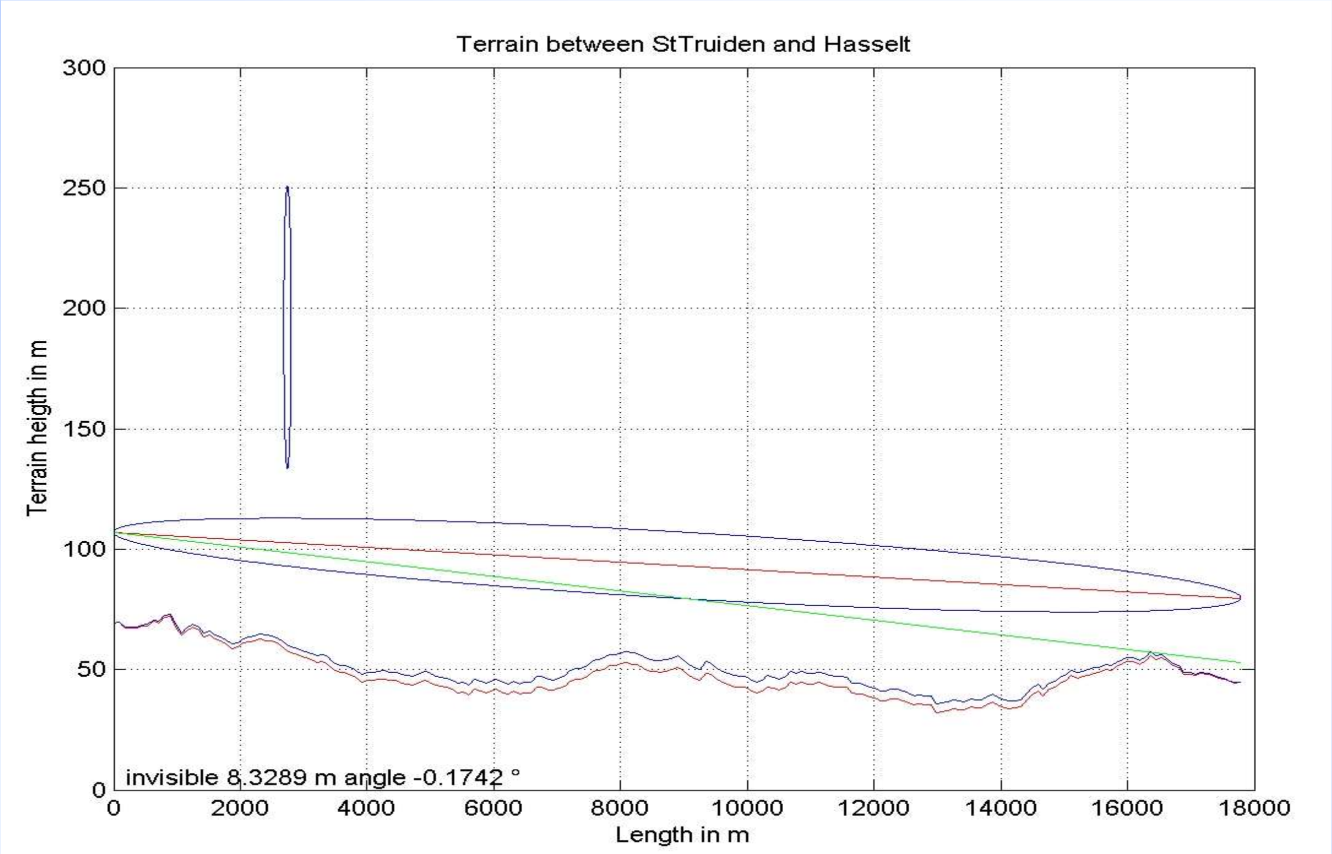
- For a terrestrial link $h \ll R_a$ and $\psi \approx 0$, so that

$$K = R_{eq} / R_a \cong 1 / \left[1 + R_a / n\left(\frac{dn}{dh}\right)\right]$$

- For the standard atmosphere K=4/3 since $n \approx 1$, $dn/dh \approx$-0.0039*10^{-6} and $R_a \approx$ 6378137 m in the WGS84 ellipsoid.

Link in the presence of a wind turbine

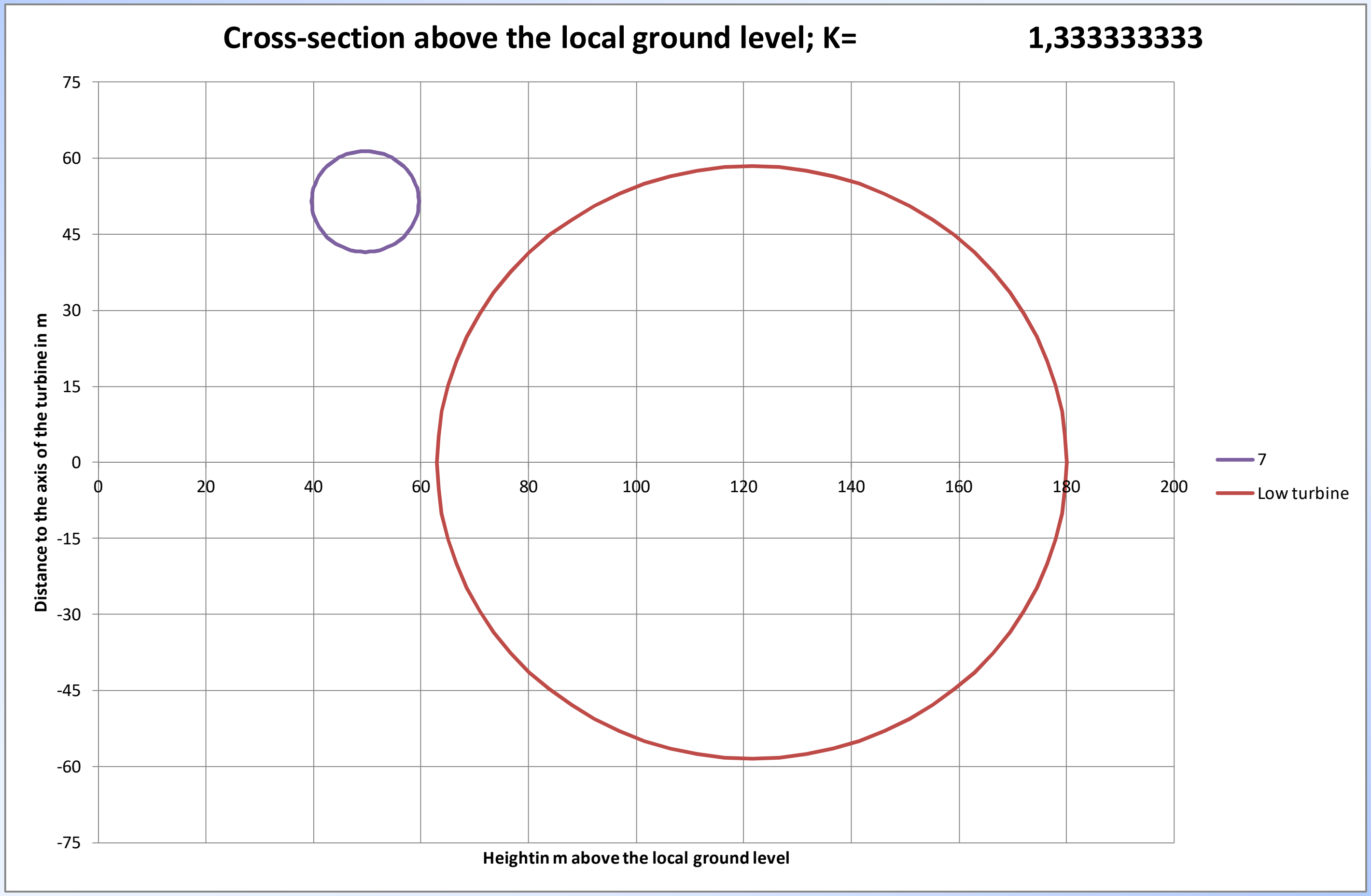
- With terrain data from the Shuttle Radar Topography Mission



- No spatial interference in the standard atmosphere

Links in the presence of a wind turbine

- Cross section OK in normal propagation crcumstances



Links in the presence of a wind turbine

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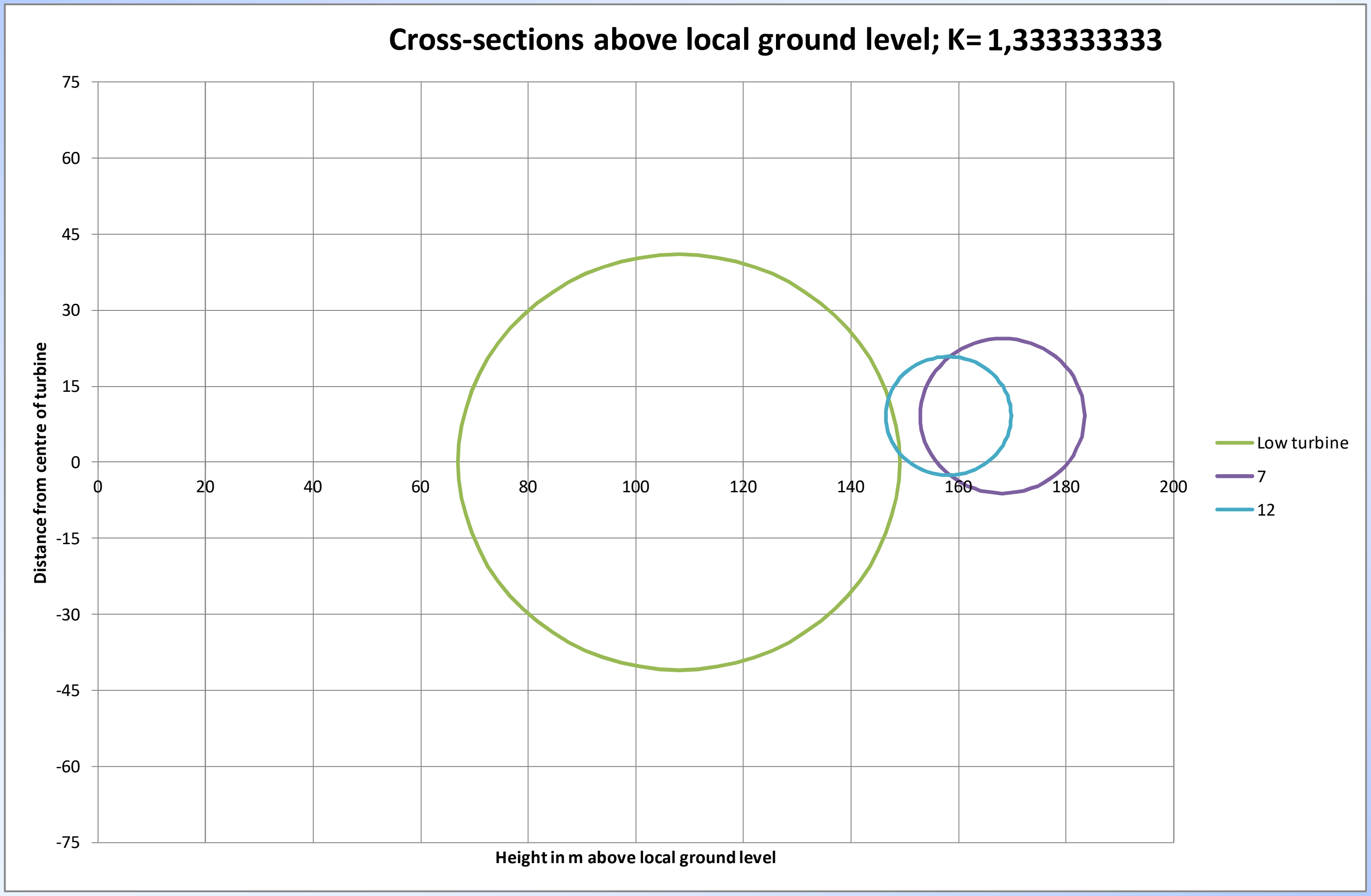

Meteorological measurements

- Regularly (till 2003 twice daily, since 2003 3x per week) a weather balloon is launched. It records all needed variables in function of the altitude *h* above the local ground level at the headquarters of the Royal Meteorological Institute

Determination of extreme propagation conditions

- We have to compute not only *n*, but also *dn/dh*

$$\frac{dn}{dh} = 77.6*10^{-6}[\frac{dp}{dh} + \left(4810/T - 0.072\right)\frac{de}{dh}$$

$$-\left(p - 0.072e + 9620e/T\right)/T\frac{dT}{dh}]/T$$

- Based on balloon data between January, 1, 1968 and December, 23, 2016, the following extreme values have been found:

Variable	Dimension	Minimum	Maximum
T_s	K	256.050	307.150
P_s	hPa	946.000	1110.400
e_s	hPa	0.278	29.941
dT/dh<200	K/m	-0.107	0.060
dp/dh<200	hPa/m	-0.403	-0.107
de/dh<200	hPa/m	-0.105	0.050

Determination of extreme propagation conditions

- The refractivity N=(n-1)*10[6] varies between

$$N_{\max} = 77.6 / T_{\min}\left[p_{\max} - (0.072 + 4810 / T_{\min})e_{\max}\right]$$

- and

$$N_{\min} = 77.6 / T_{\max}\left[p_{\min} - (0.072 + 4810 / T_{\max})e_{\min}\right]$$

- or between 77.7 and 506.3
- The 3 terms in dn/dh are

$$\frac{dn}{dh} = ct_1\frac{dp}{dh} + ct_2\frac{de}{dh} + ct_3\frac{dT}{dh} = t_1 + t_2 + t_3$$

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Determination of extreme propagation conditions

- The coefficient first term varies between 0.253*10-6 and 0.303*10-6 [1/hPa]

$$ct_{1,\max} = 77.6*10^{-6} / T_{\min}$$

- The coefficient of the second term varies between 3.938*10-6 and 5.671*10-6 [1/hPa]

$$ct_{2,\max} = 77.6*10^{-6}\left(4810 / T_{\min} - 0.072\right) / T_{\min}$$

- The coefficient of the third term varies between

$$ct_{3,\min} = -77.6*10^{-6}[p_{\max} + (9620 / T_{\min} - 0.072)e_{\max}] / T_{\min}^{2}$$

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Determination of extreme propagation conditions

- So, *dn/dh* varies between $-0.876 \cdot 10^{-6}$ and $0.539 \cdot 10^{-6}$ [1/m]
- This allows us to compute the extreme values of K
- They are between

$$K_{max} \cong 1 / \left[1 + R_a / n_{min} \left(\frac{dn}{dh} \right)_{min} \right]$$

and

$$K_{min} \cong 1 / \left[1 + R_a / n_{min} \left(\frac{dn}{dh} \right)_{max} \right]$$

- So, $K \leq -0.218$ or $K \geq 0.225$

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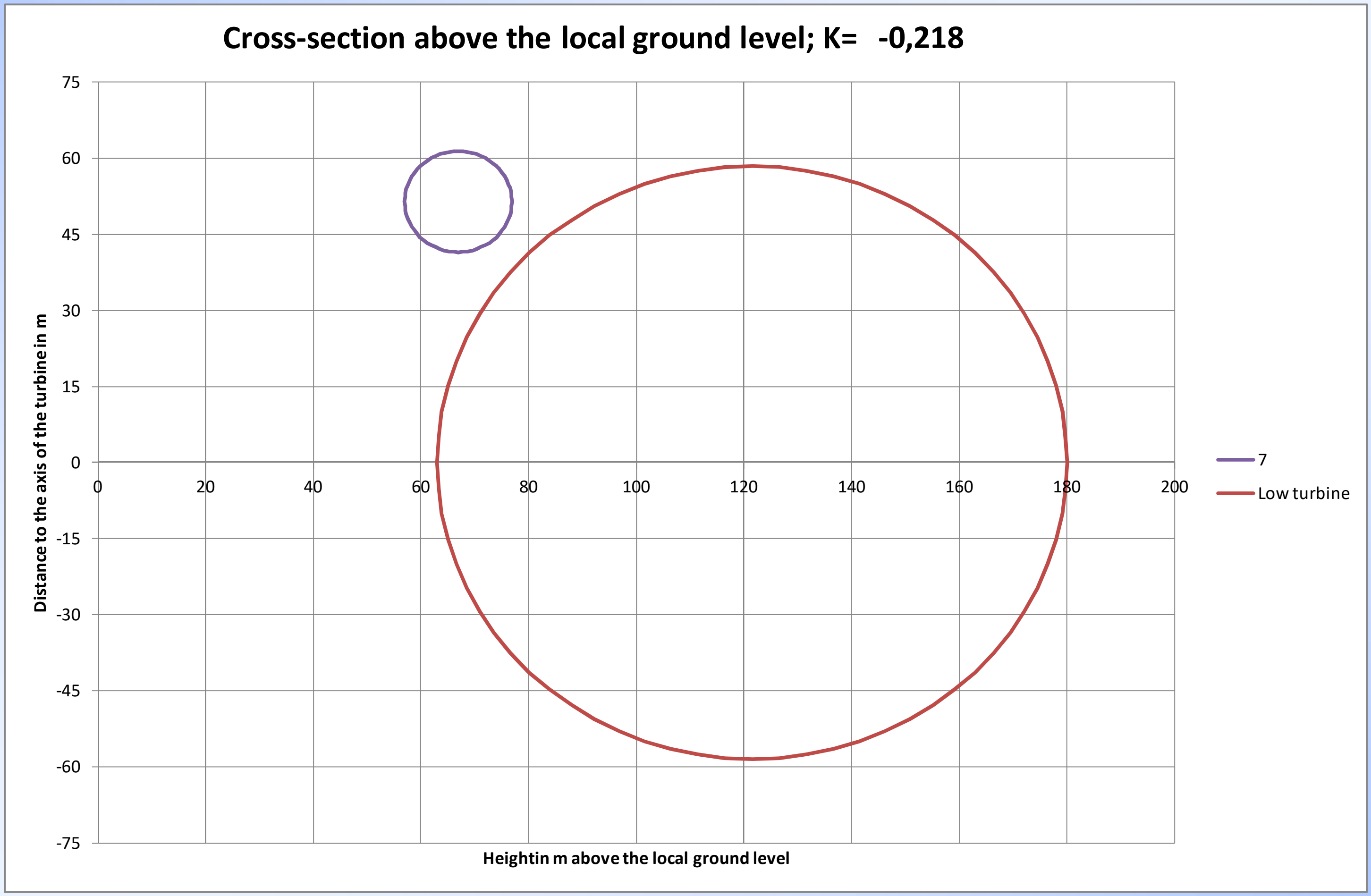
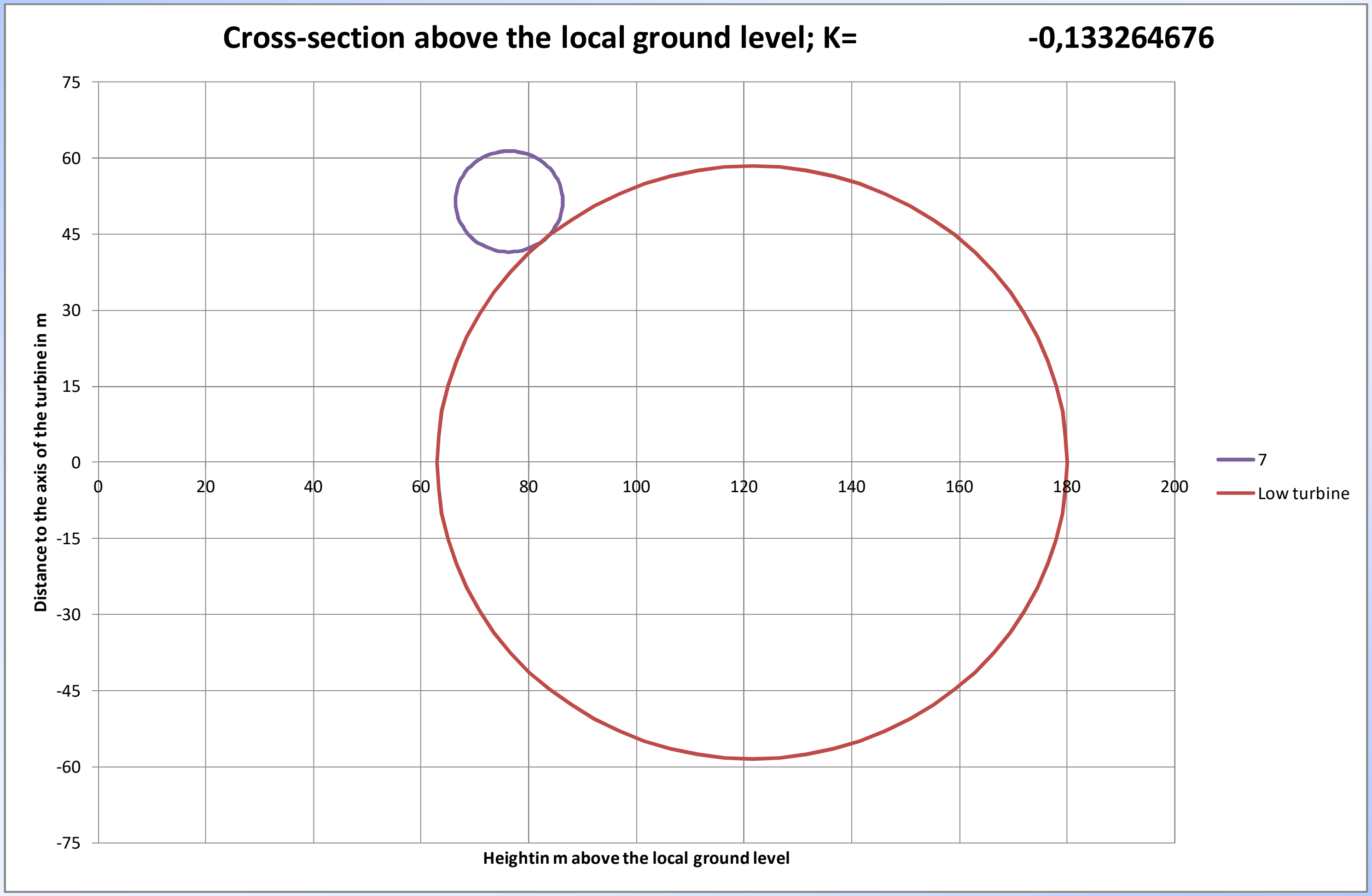
Links in the presence of a wind turbine

- Cross section of first link also OK in extreme propagation



Links in the presence of a wind turbine

- Propagation might even be more extreme (up to K=-0.1332)



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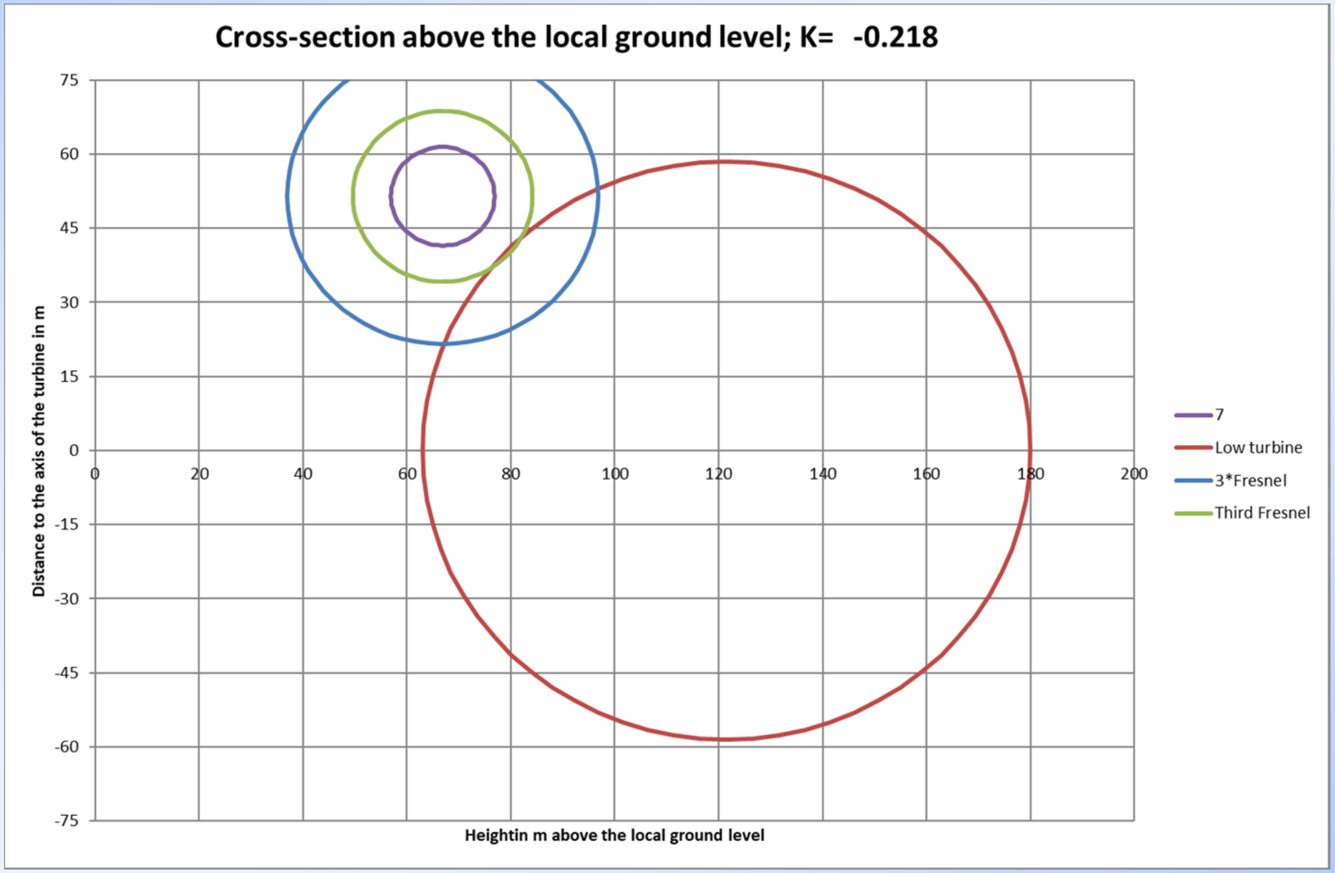
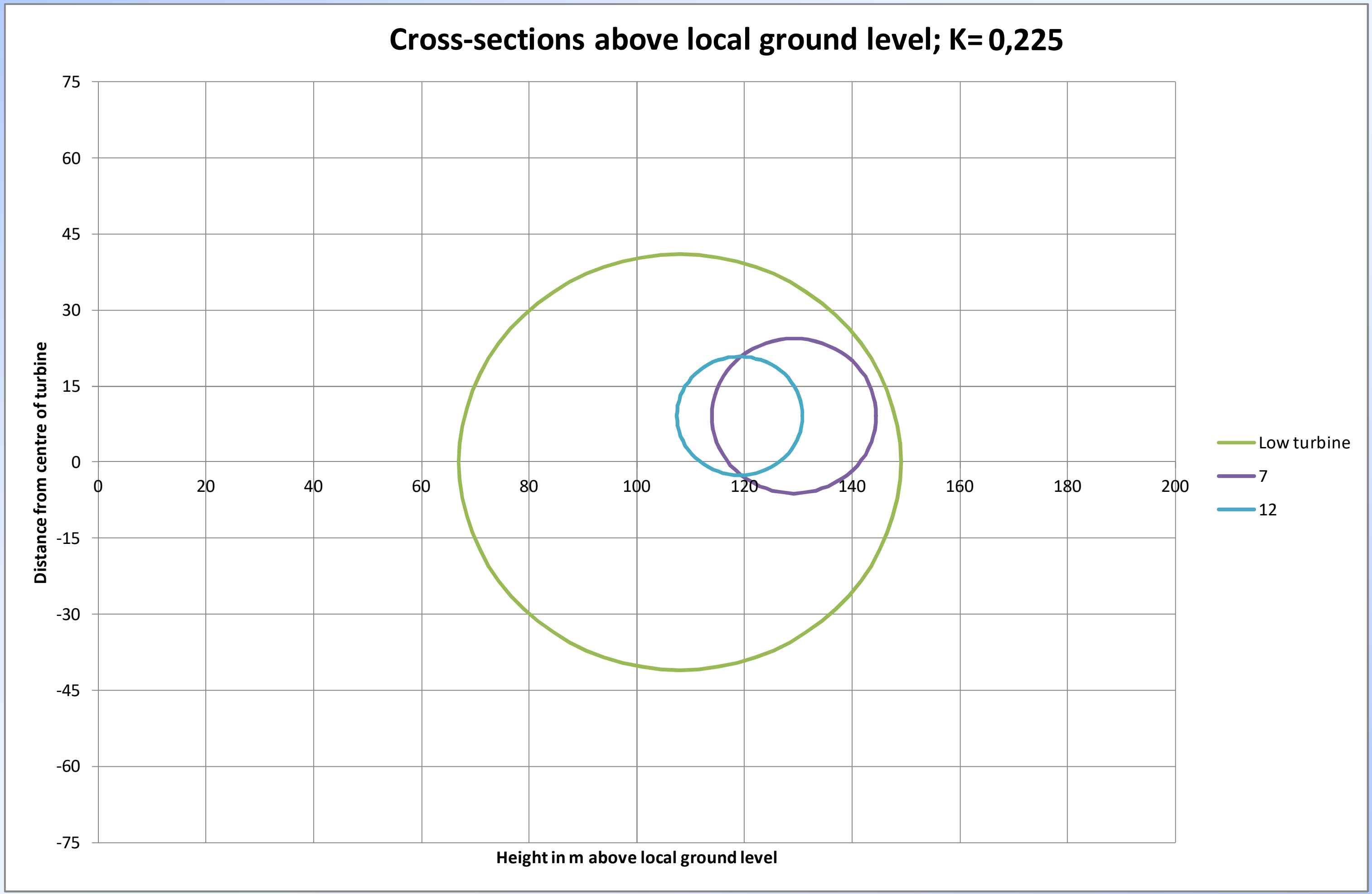
Links in the presence of a wind turbine

- Also the more stringent requirements might be fulfilled (third Fresnel ellipsoid but not 3x the first ellipsoid)



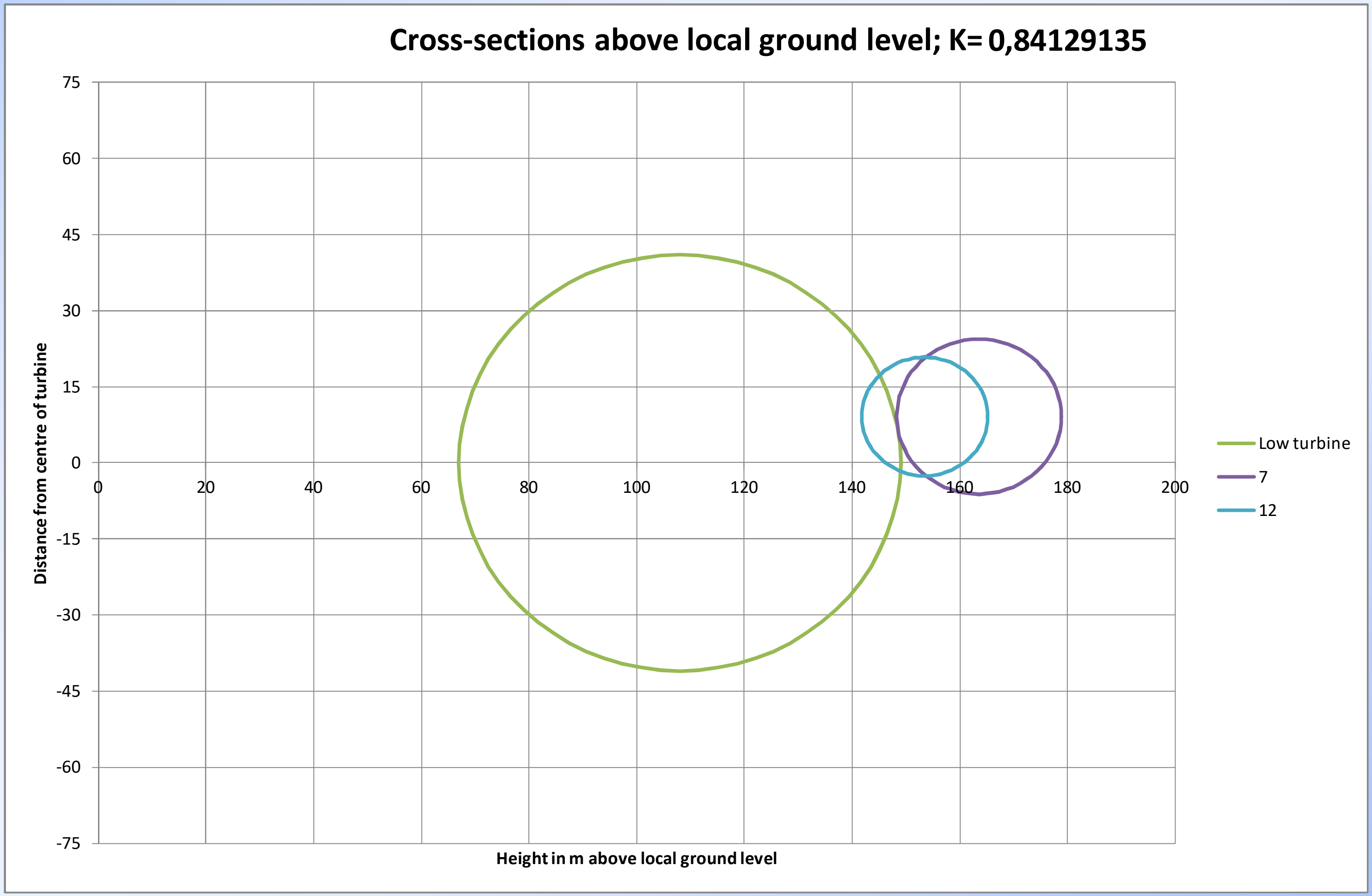
Links in the presence of a wind turbine

- Second link not OK any more in extreme propagation



Links in the presence of a wind turbine

- Only up to K=0.8413 could be allowed for the second link, not lower.



Conclusions

- Analysis of the worst case behaviour of microwave links for Belgian meteorological conditions are investigated.
- This should allow to predict more accurately the effects of obstacles like wind turbines on existing microwave links.
- The examples are computed for a company wanting to install new wind turbines.
- Thank you. Questions?

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