“RADAR, RADIO AND WIND TURBINES”

Wind Turbines in the Radiation Field of Systems from a Prediction and Siting Point of View

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NAVCOM Consult

⇨ Consultancy Company for services in aviation

Navaids -, Landing -, Radar -, Comm-Systems

3D – Numerical System Simulations

⇨ Founded by Dr.-Ing. Gerhard Greving in 1997

⇨ Team of former R&D and System Engineers (SEL, Alcatel, Thales)

⇨ Network of Specialists and cooperating companies

⇨ Worldwide activities on wind turbines since about 10 years

⇨ Independant Consultancy/Expertises

Internet-addresses for download of Papers

Radar-, Navaids-, Landing-, Comm-Systems

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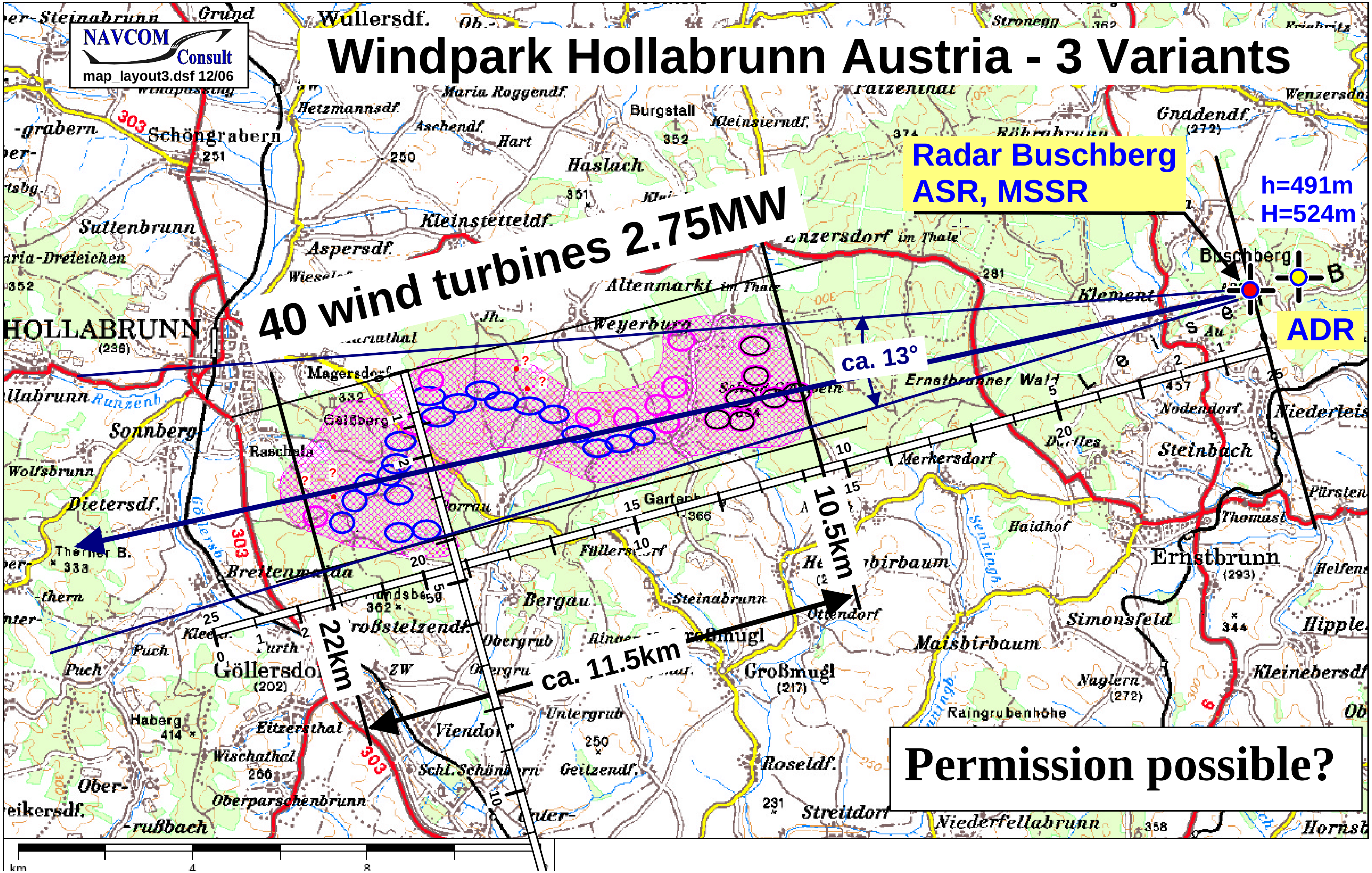
IRS 2006 / Krakow	http://www.navcom.de/irs2006pt.pdf
IRS 2005 / Berlin	http://www.navcom.de/irs2005pt.pdf
ISPA 2004 / Munich	http://www.navcom.de/ispa2004pt.pdf
IRS 2003 / Dresden	http://www.navcom.de/irs2003pt.pdf
IRS 2007, EURAD 2007	Radar Conferences, Papers submitted

More on request

Content

- ⇨ General examples of planned windparks and related systems
- ⇨ Introduction
- ⇨ Radar Types (and windturbines)
- ⇨ Specs and definition of distortions
- ⇨ windturbines and windparks
- ⇨ System simulations (modeling, numerical methods)
- ⇨ RCS
- ⇨ Examples
- ⇨ Measures for Improvement; Stealth, absorbers
- ⇨ Concluding Remarks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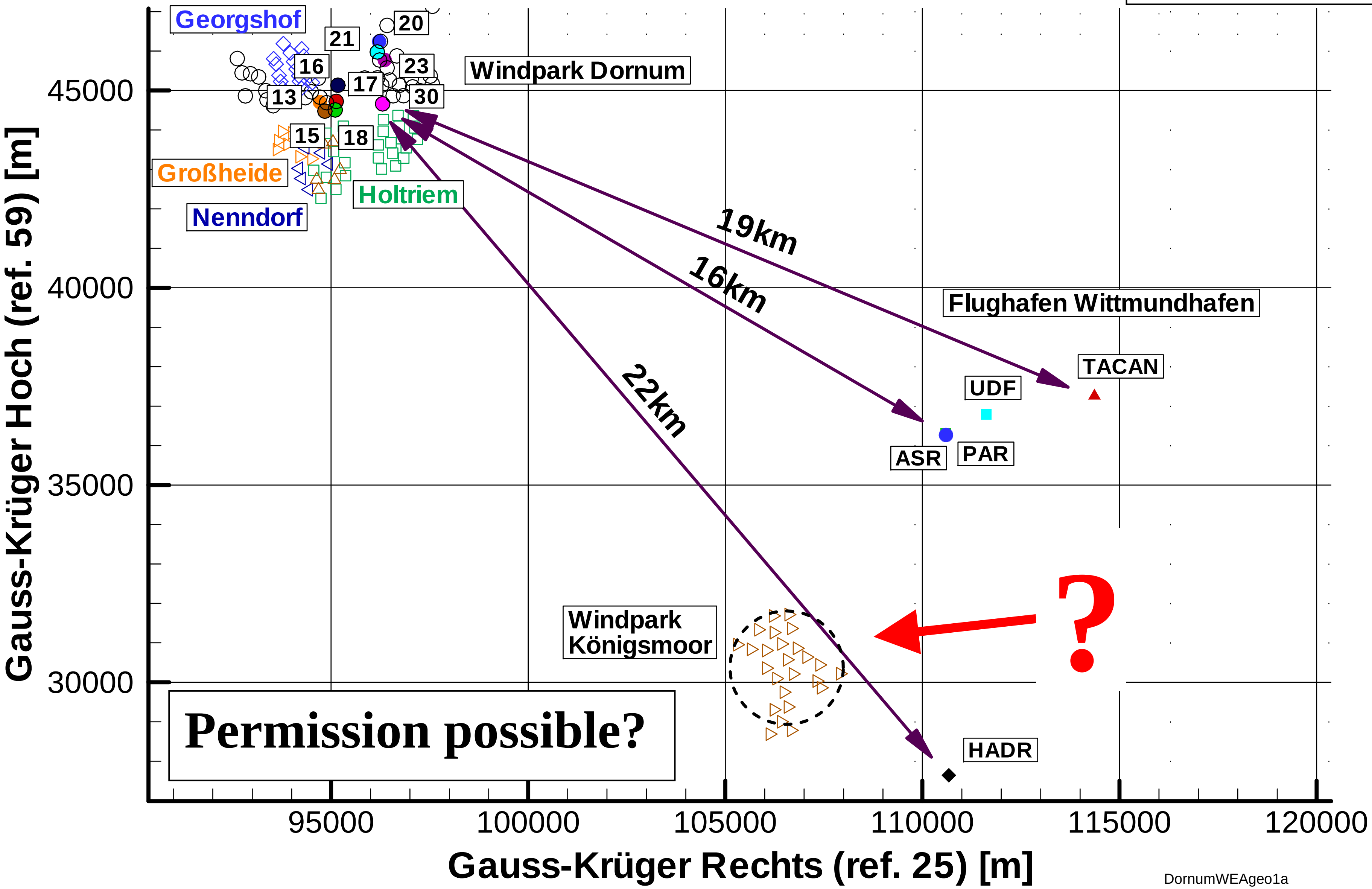
map_layout3.dsf 12/06
Windpark Hollabrunn Austria - 3 Variants
40 wind turbines 2.75MW
Radar Buschberg
ASR, MSSR
h=491m
H=524m
ADR
ca. 13°
10.5km
22km
ca. 11.5km
Permission possible?

Windpark Dornum und Umgebung

Flughafen Wittmundhafen; TACAN, HADR

Example 2
Germany



Permission possible?

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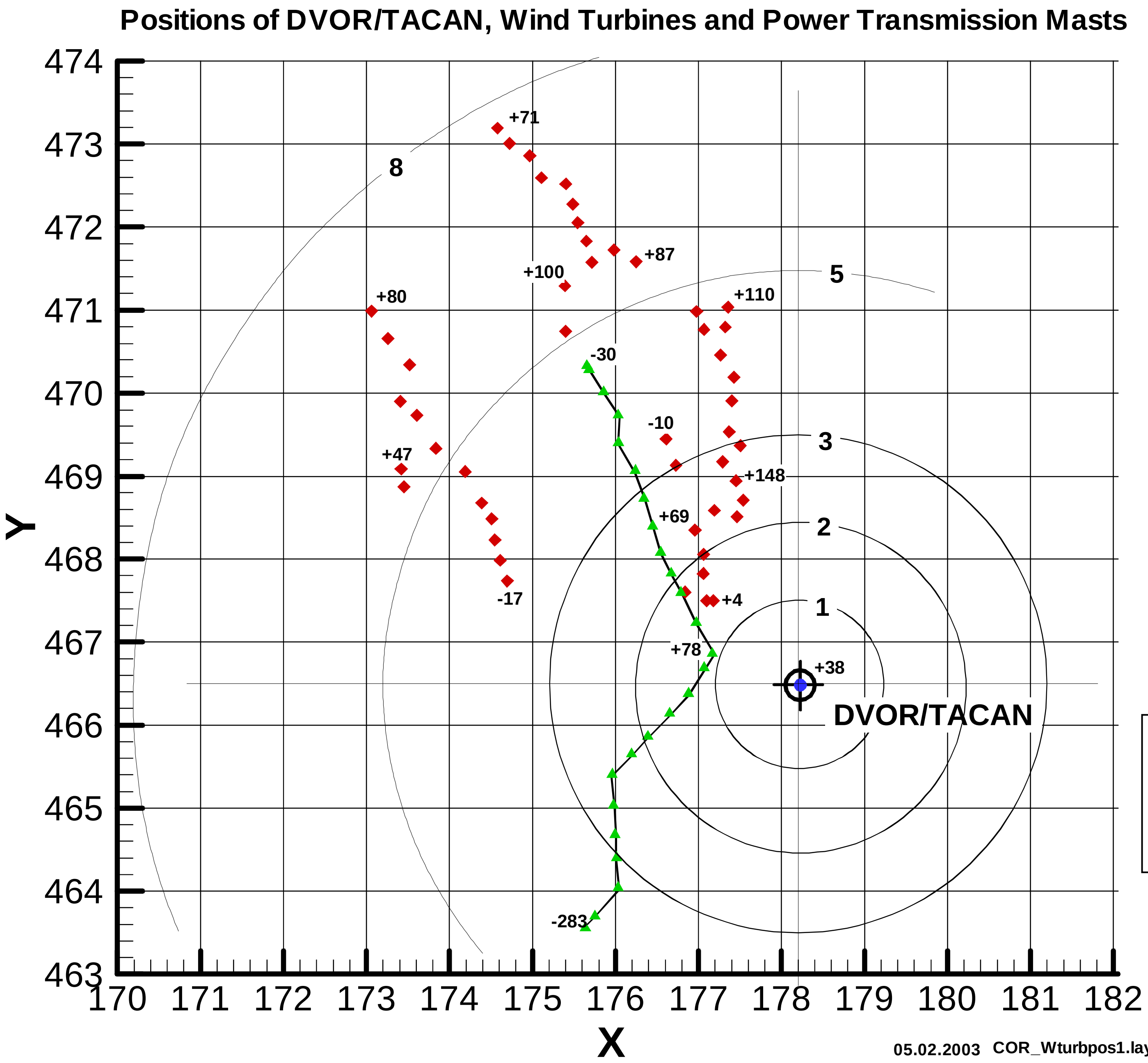
COR_Wturbpos2.dsf 03/04

Wind Park with 49 Generators
DVOR/TACAN/DME - Korea

Example 3
Korea



Permission possible?
Conditions?

Typical Situation - Building Application
What to do ?

- ⇨ **Building application for a wind turbine or wind park**
- ⇨ **Navaids-, Radar-, Comm-Systems are in some distance**
- ⇨ **Does the realized wind park harm the operation of system(s)?**

  Specifications
  Risk, Safety ←→ 0% risk, 100% safety impossible
  “comfort”

- ⇨ **different scenarios** **different types of windturbines,**
  different geometries (distance, accumulation)
  different systems

- ⇨ **Can be answered/solved only <u>in advance</u> by reliable simulations**
  State-of-the-art methods and principles !

Wind turbines in the radiation field of systems

Radar-, Navigation-, Landing-systems, Communications

ASR/PSR

SSR/MSSR

IFF

ADR HADR

RAT-31S

DME

PAR

TACAN

GPS

ILS MLS

VOR/DVOR

ADS-B

weather radar S/C

NDB

VHF/UHF com

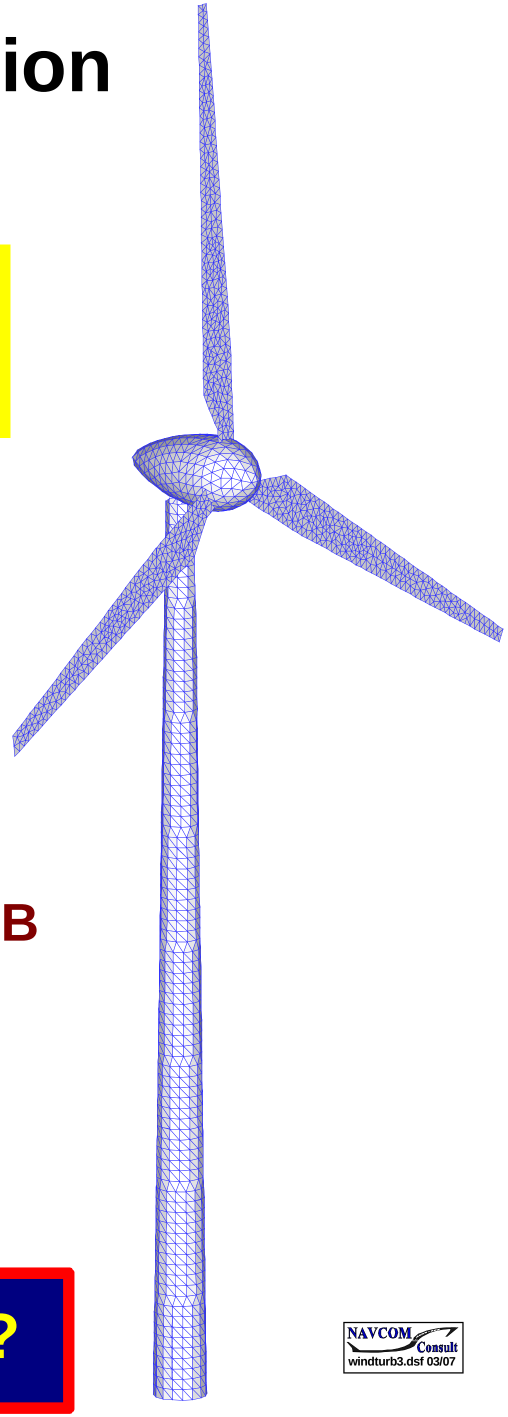
WAM

radio relay

ADF/UDF

●●●

effects / distortions / conditions ?



NAVCOM Consult windturb3.dsf 03/07

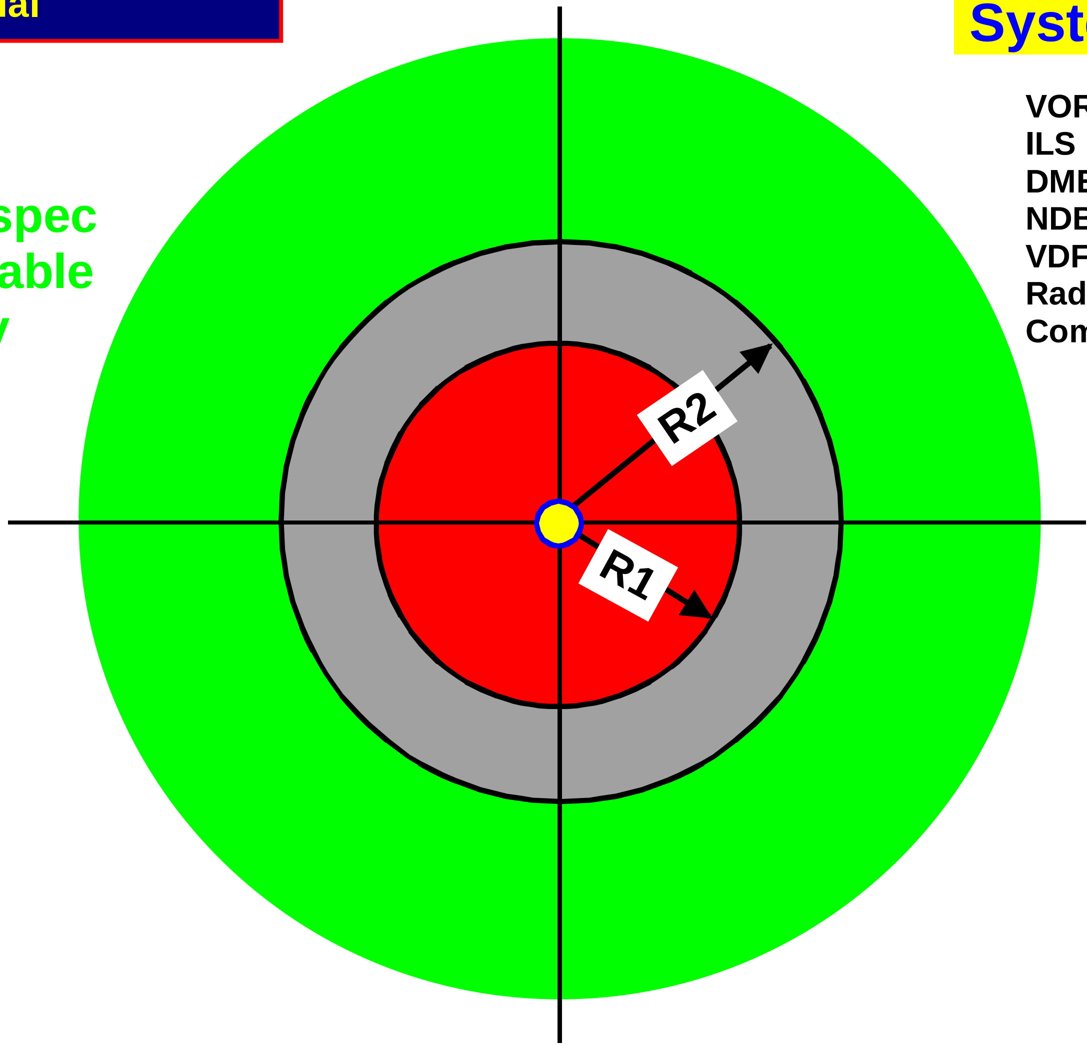
Classification of objects - Threat to systems

Basic generalized assumptions for objects
dimensions, forms/shapes, material

>R2 "green" = signals safely in spec
objects safely tolerable
no study necessary

>R1, <R2 "grey" = indifferent
to be studied in more depth
may be acceptable

<R1 "red" = unsafe
generally out of spec
objects not tolerable
modifications necessary



System

VOR/DVOR
ILS
DME
NDB
VDF
Radar
Comm

Systems and General Classification

Windturbines and

Navigation-

Landing-

Radar- **(civilian ATC, military, Meteo)**

Meteo-radar measure amplitudes/speed !

Communication-

Activities of NAVCOM Consult on all fields in
A, B, D, F, GB, H, HK, I, K, L, …

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System Specifications and Requirements (1)
Facts and Aspects

⇨ **Balance between interests of systems and "windturbines"**

⇨ **Specifications and requirements should be along "needs of systems"**

Real needs (necessities, facts) ←→ wishes, comfort, ("nice to have")

Worst-(worst)-case assumptions

Neglect, delete given natural distortion effects

Made often/mostly by unilateral interests of the systems (providers, …)

100% safety and 0% risk not possible

"no distortions" ←→ no loss of plots ←→ probability of detection #100%

⇨ **Specifications / Requirements sometimes exaggerated and prohibitive**

e.g. No visibility of windturbines for primary radar → 30km, 50km, 100km

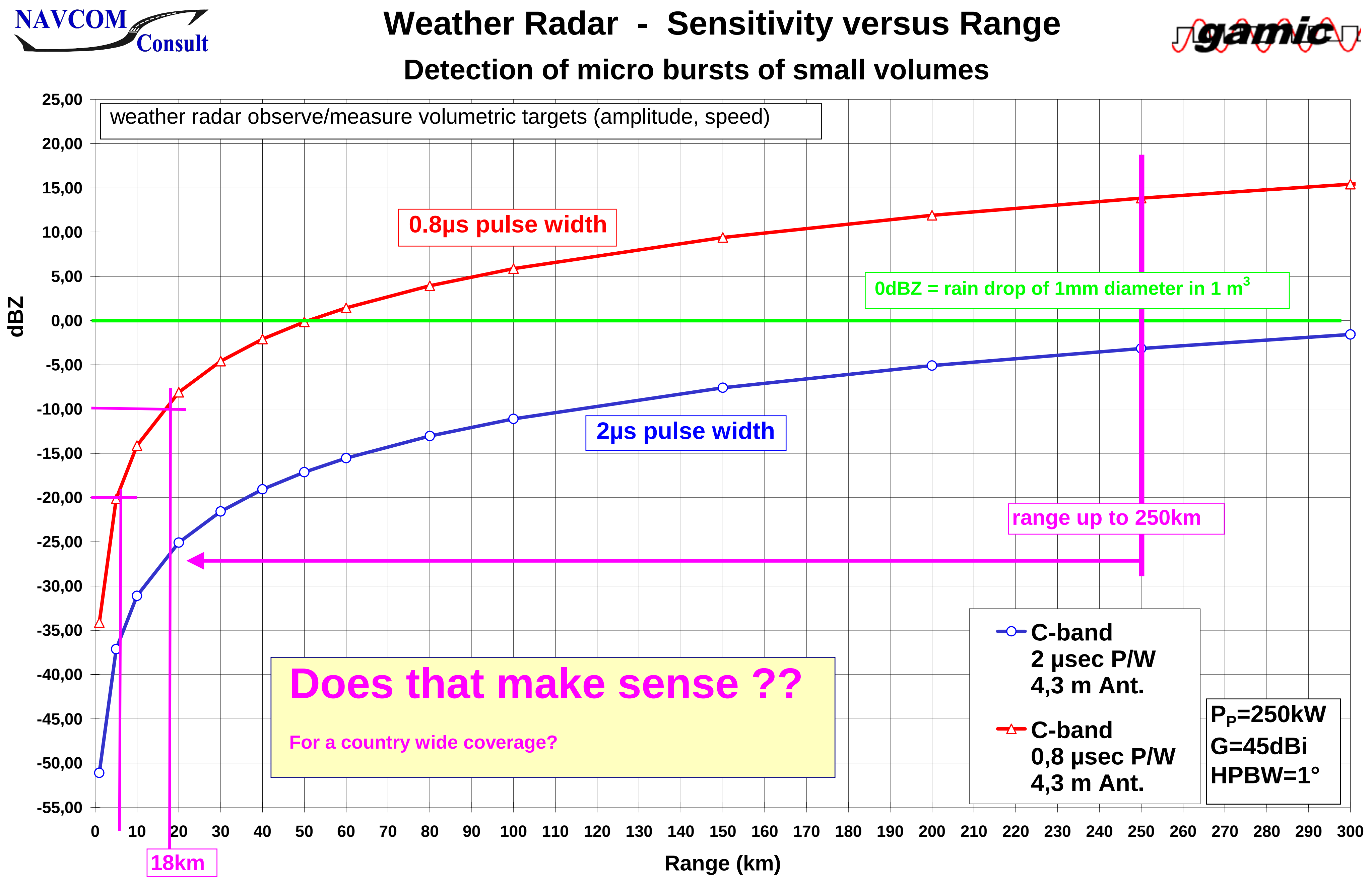
It is the basic task of the primary radar to "see" objects

e.g. detectability of -10dBZ (-20dBZ) for weather radar

Range is much reduced → loss of overlapping coverage

Weather Radar - Sensitivity versus Range

Detection of micro bursts of small volumes



System Specifications and Requirements (2)
Facts and Aspects

- ⇨ **Systems often do not use modern / adapted capabilities**
- ⇨ **Observed effects not questioned and transferred to other systems**
- ⇨ **Measurements taken as absolute and un-questionable**
  - **Interpretation of results**
  - **Measurements made for a certain system at a certain site under certain conditions**
- ⇨ **Often worst-worst case assumptions**
- ⇨ **Often a "lot of safety margins"**

⇨ **Can the mission/task of the system be met ?**

Radar Types and Classification (1)

Basic Radar Types (not complete) ←→ wind turbines

Criteria for different types

Use	civilian, military ←→ Meteo, (weather channel of ASR)
Function	surveillance, guidance, air defence
Frequency	VHF - L-band - S/C-band - mm-wave
Technology	2D, 2.5D, 3D, mechanically rotating, hybrid, phased array, beam forming CW, pulse, pulse Doppler MTI (stationary objects, clutter suppression) MTD (velocity measurement; speed of aircraft, clowds) Monopulse 1D, 2D (Σ, Δ, Ω) pencil beam, cosekans pulse compression polarization linear vert/hor, circular signal processing (PRF, STC, CFAR, …) fixed, variable frequency

Radar Types and Classification (2)

Primary radar *(evaluation of back scattering; "reflections")*

Civilian ATC (L, S)

Military ATC, short / mid / long range)

Weather radar (S, C) ←→ weather channel of primary radar

Secondary radar (ATC, SSR/IFF; WAM, ADS-B)

Not a radar in the strict sense

Ground surveillance

ASDE, SMR, SMGCS

Weather radar

Civilian vs military ATC radar

- ⇨ **ATC-radar :** ASR primary radar SSR/MSSR/IFF

  and/or collocated

- ⇨ **civilian ATC :** ASR primary radar SSR/MSSR

- ⇨ **military ATC :** ASR primary radar SSR/MSSR/IFF
  (may have weather channel)

- ⇨ **each country (civilian/military) seems to have a different policy**

- ⇨ **some countries switch off or deinstall ASR primary radar**

Applicable Specifications

- ⇨ ICAO Annex 10 Vol. I SARPs
- ⇨ ICAO Annex 10 Vol. IV SARPs, no multipath spec
- ⇨ ICAO Annex 10 Vol. V SARPs
- ⇨ ICAO Doc 8071 (guidance material)
- ⇨ EUROCONTROL SUR.ET1.ST01.1000-STD-01-01 Radar
  EUROCONTROL SUR.ET1.ST03.1000-STD-01-01 Radar
- ⇨ national specifications /rules may exist
- ⇨ MIL
  For military radar often no open or applicable specs exist at all

Distortions of Systems

⇨ **What is a "distortion" ? ←→ violation of specification**
Risk, danger, safety ←→ "comfort"

⇨ **Does a specification for the system in question exist ?**

⇨ **No distortions, 100% safety, 0% risk, PoD 100%**
←→ impossible, unrealistic

⇨ **What is an acceptable distortion ? ←→ within specs, …**

⇨ **Is the pure visibility of windturbines by the primary radar a distortion ? (no, it's the task of a radar to see obstacles?)**

←→ "comfort"

⇨ **Modern radar technology and modern signal processing can cope windturbines widely → better coexistence**
(if not too close)

Basic Effects on Radar

Shadowing	(range reduction at the limit)
Amplitude errors	(weather radar, precipitation)
Range errors	(…)
Clutter	(←→ MTI ←→ MTD)
False targets/interrogations	(by reflections / multipath; ATC SSR) Stationary object is not a target
Angle errors	(by scattering; monopulse Δ/Σ)
Speed error	(e.g. weather radar, wind speed)

On signal processing (CFAR, “track processor”; (helicopters))

Saturation, “desensitizing” ….(loss of plots, …. CFAR)

Different relevance for different radar types

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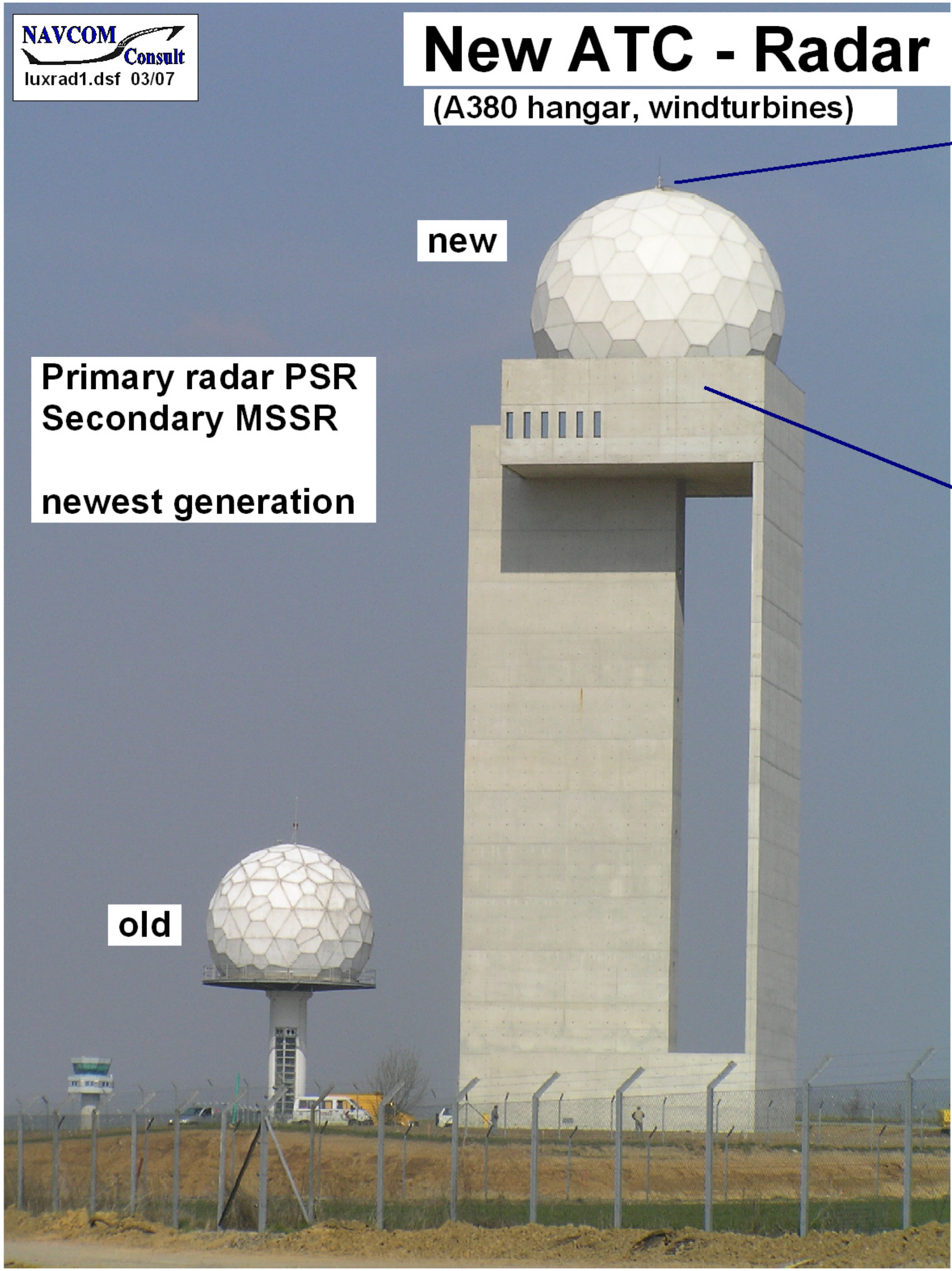
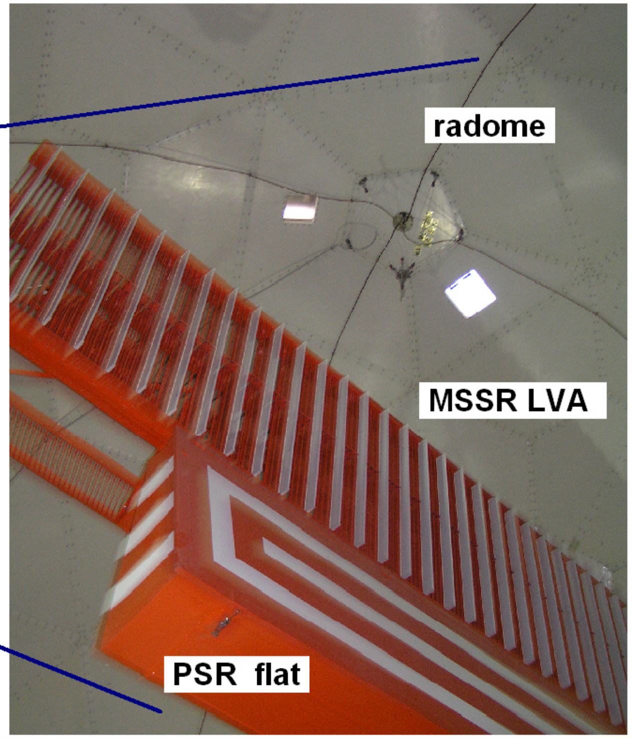
luxrad1.dsf 03/07

New ATC - Radar LUX

(A380 hangar, windturbines)





Wind turbines, wind parks

Different types and sizes of windturbines

Different sizes and layouts of windparks

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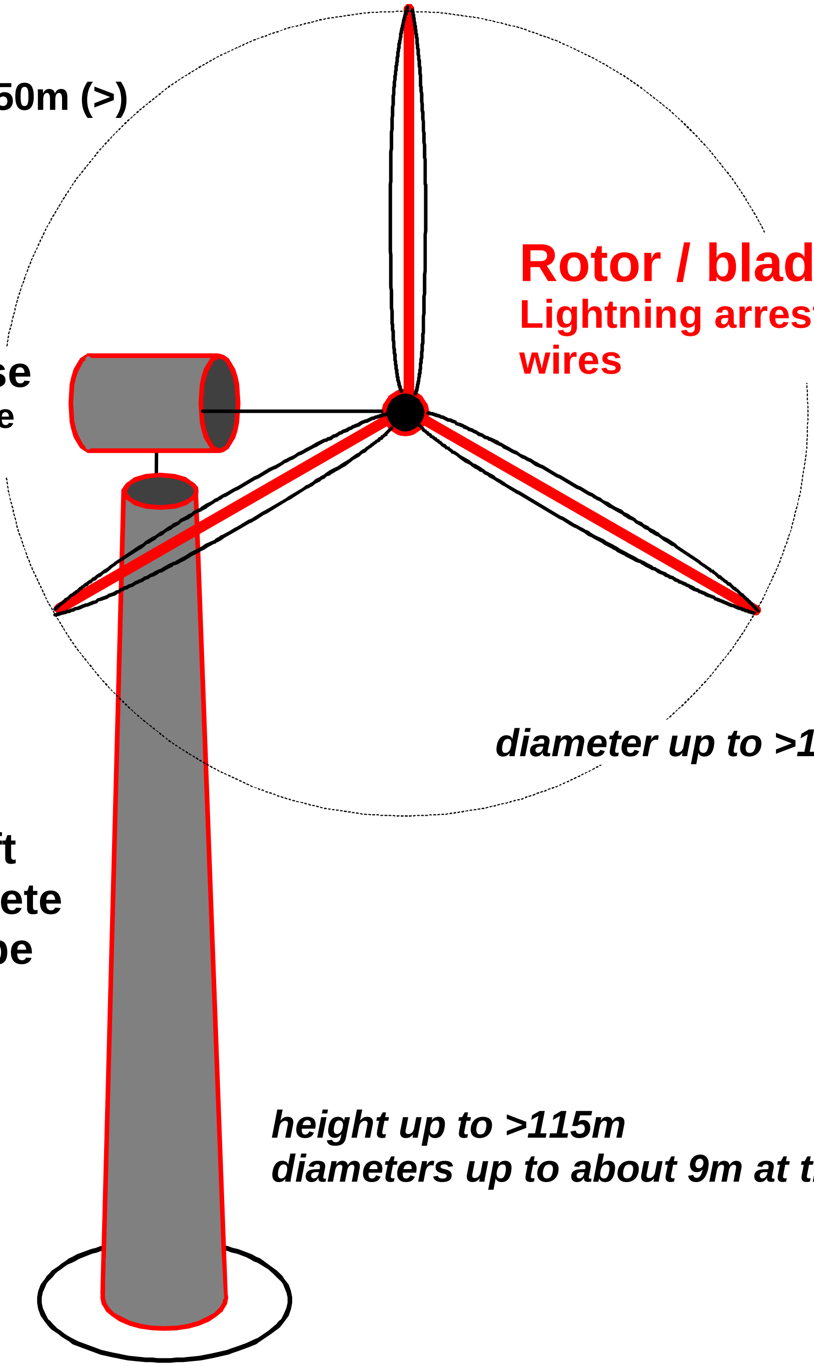
windparts3.dsf 11/06

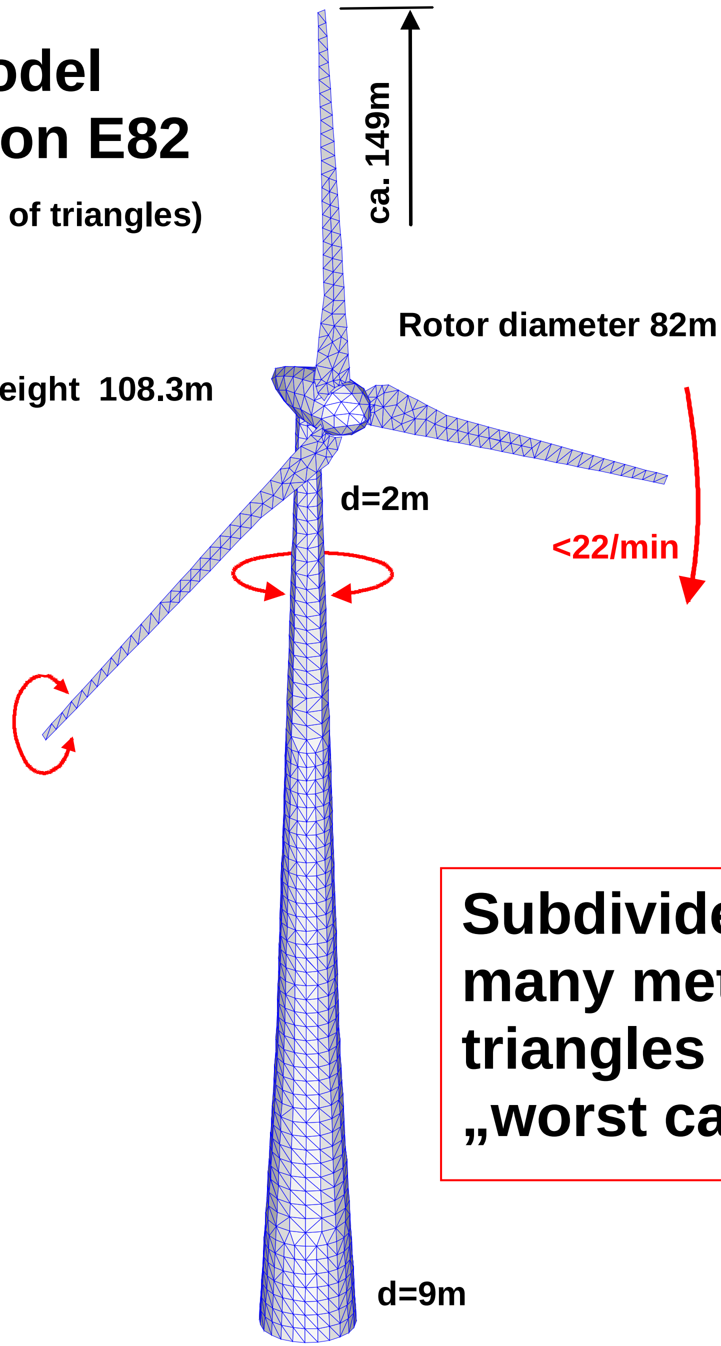
Main parts of a wind-turbine



3D-model Enercon E82

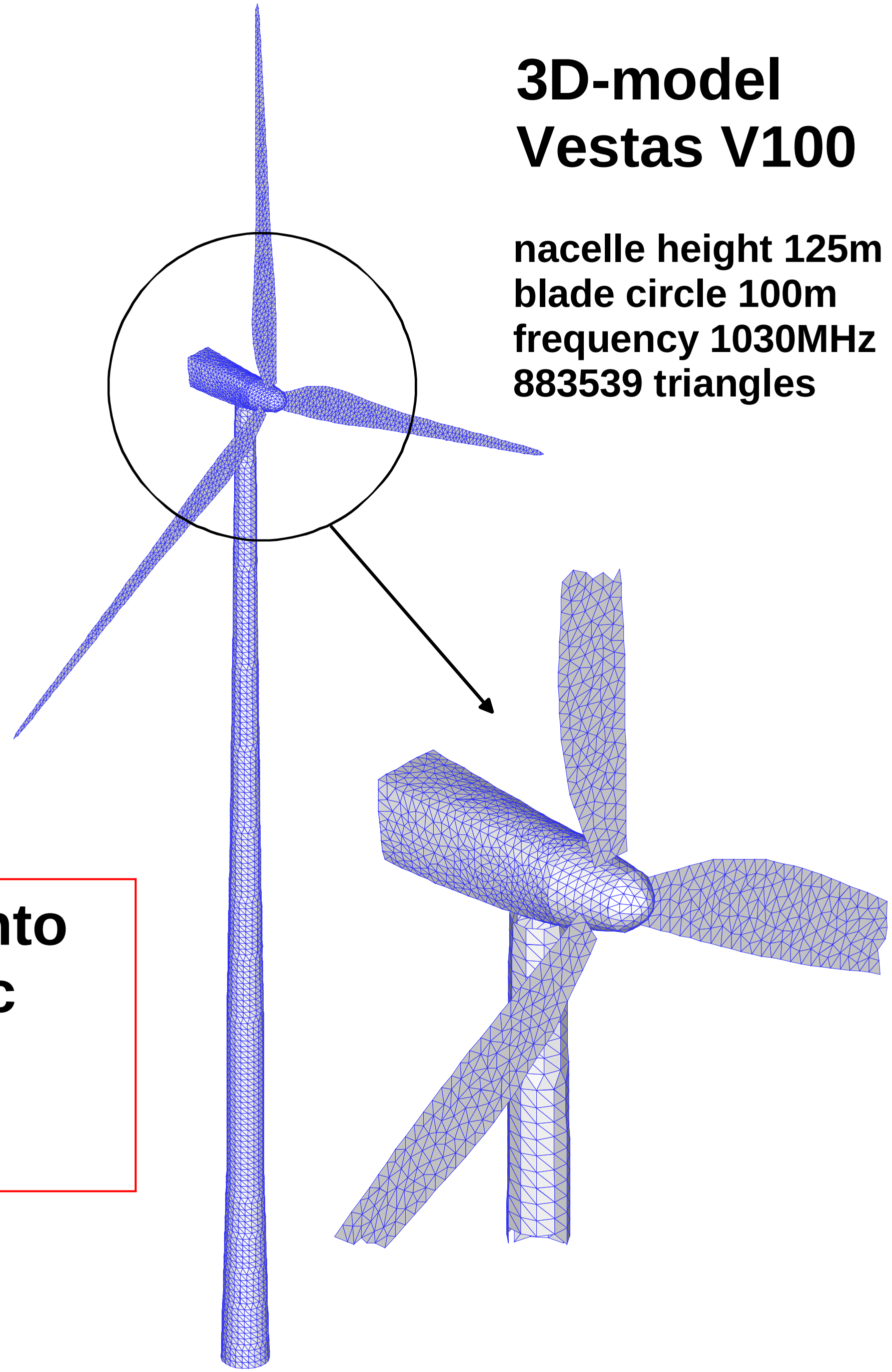
(reduced # of triangles)

nacelle height 108.3m



3D-model Vestas V100

nacelle height 125m
blade circle 100m
frequency 1030MHz
883539 triangles



Subdivided into many metallic triangles „worst case“

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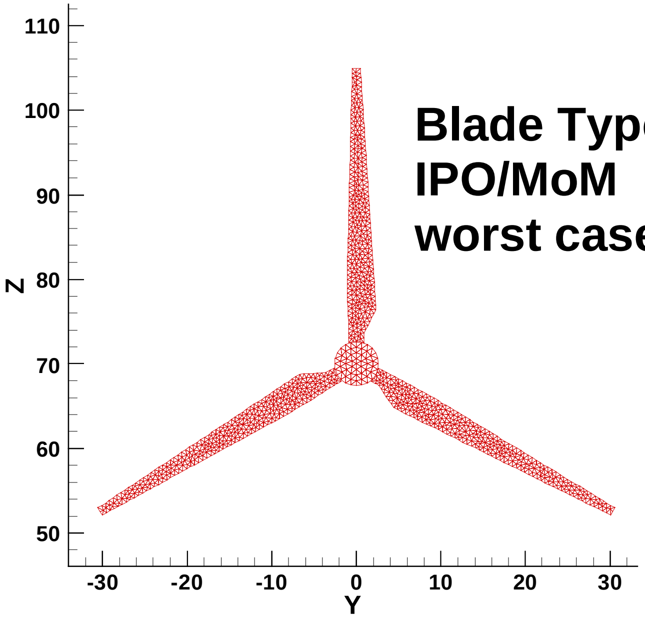
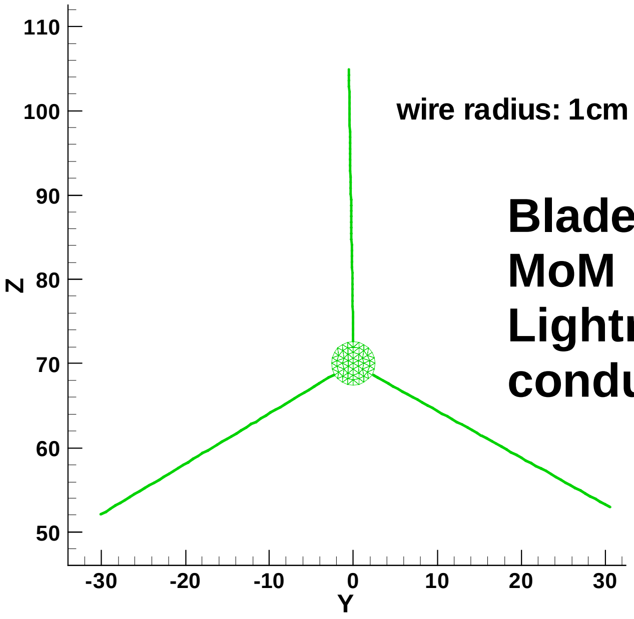
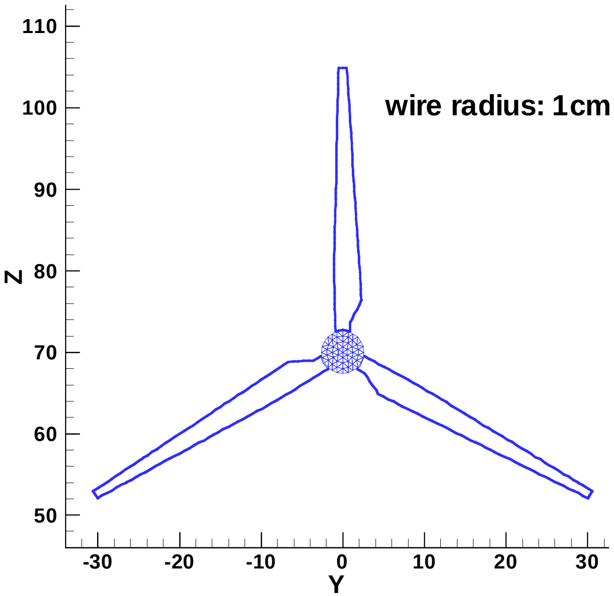
3D_E82_V100.dsf 11/06



Blade Type 1 -
IPO/MoM
worst case Metall



Blade Type 2 -
MoM
Lightning protection
conductor rod



Blade Type 3 -
MoM
Enercon
Lightning protection
system

Wind turbines Blade Models

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DVORe70blades1f.dsf 12/06

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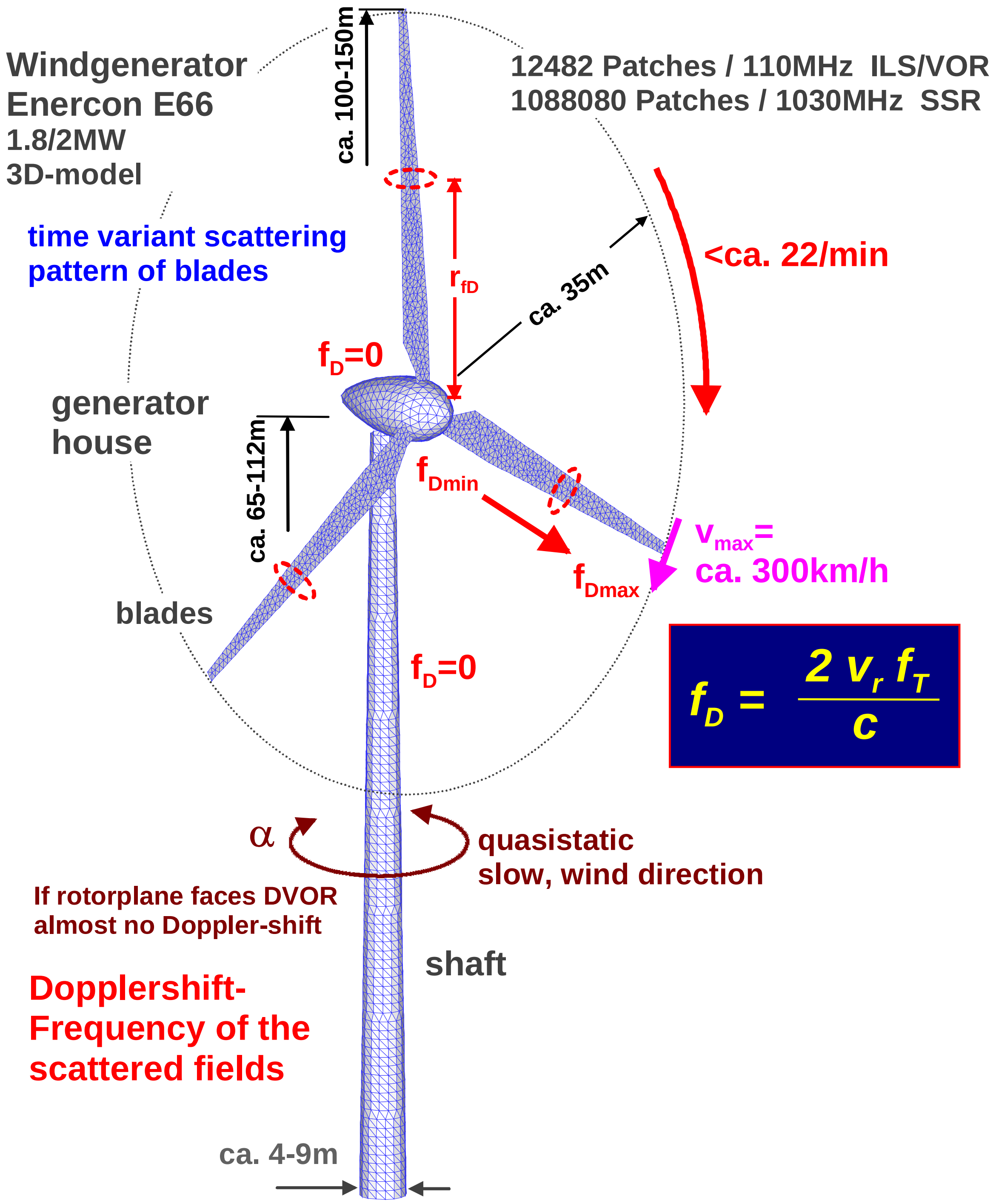
windgenere66c.dsf 03/06



$$f_D = \frac{2 v_r f_T}{c}$$

Windgenerator Enercon E66

3D-model - Doppler shift

VOR/DVOR
DME
ATC Radar
weather radar

up to 190m height
carbon fibre blades
6MW

Basic Properties of Windturbines

Main parts shaft, machine house, blades

Mechanical up to 150m/200m
Diameter of shaft ca. 9m … 2m
Blade circle 70m - 100m …
Blade rotation : up to ca. 22U/min

Material shaft : metal, concrete, lattice type
Shell of machine house : glas fibre (metal)
Blades : glas fibre, carbon fibre

Electrical reflection
Diffraction
(scattering)
shadowing
RCS ?

Radar and Windturbines WT
Electrical Specifics of Windturbines

⇨ **Very large in terms of wavelength for all radar systems**

Each of the main subparts

⇨ **time variant scattering pattern**

By wind direction	**slow changes**
By wind speed	**strong and fast variations**
Max periodicity	**controlled to max about 22/min (3 blades)**

⇨ **scattering pattern has stationary components**

By rotationary symmetric shaft (# lattice type)
By asymmetric machine house

⇨ **scattering pattern contains a Doppler spectrum (blades rotating)**

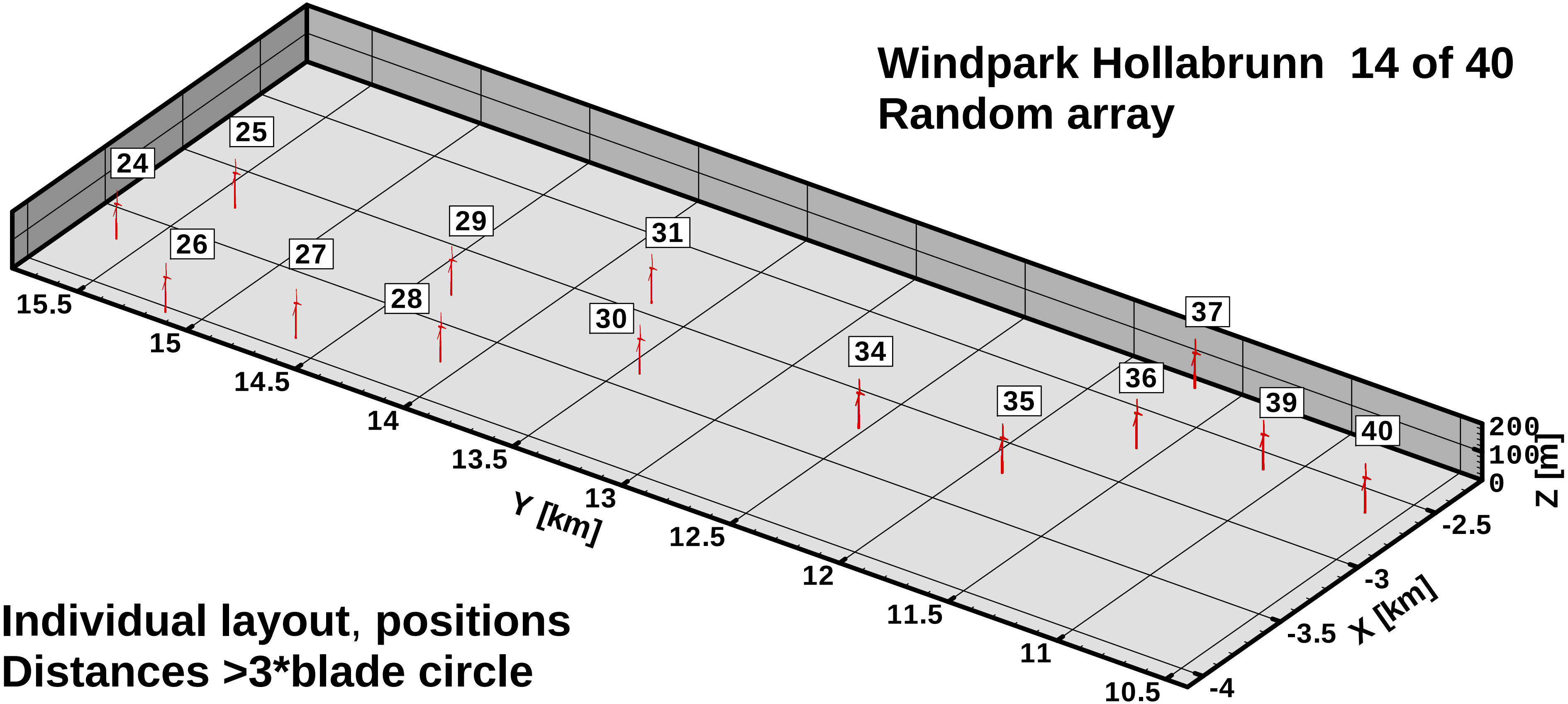
Frequency span dependant on radar carrier frequency
Frequency span dependant on wind speed

⇨ **WT have known position and basically known signature**

MSSR Buschberg (W_MSSRBG)

Windpark "Hollabrunn" - WEA 24 - 31, 34 - 37, 39, 40 (ϕ=0°, β=0°)
(MSSR: X/Y = 0/0)

Windpark Hollabrunn 14 of 40
Random array



Individual layout, positions
Distances >3*blade circle
Naturally different heights
> wave length

W_MSSRBG_Hollabr_WEAcomb2_geo1

RCS - Radar Cross Section

“A helpful term/quantity in classical radar analysis”

- → **Identification of objects in the air**
- → **Classification of objects in the air**

Also for wind turbines ?

- → **Wind turbines are installed on the ground**

⇨ Definition IEEE Std 211-1997 → KNOTT …, SKOLLNIK …

Radar cross section (scattering cross section) RCS

The projected area required to intercept and isotropically radiate the same power as a scatterer (target) scatters towards the receiver.

The scattering cross section is calculated from the relationship

$$\sigma_{pq} = \lim_{R \to \infty} \left[4\pi R^2 \frac{\left|E_p^s\right|^2}{\left|E_q^i\right|^2} \right]$$

R is the distance between scatterer and receiver

E_p^s is the p-polarized component of the scattered field at the receiver

E_q^i is a q-polarized incident electric field at the scatterer

The incident field is assumed to be planar over the extent of the target.

This is the most general definition of the RCS which includes the polarization. The polarization may be different for the excitation and the evaluation.

Monostatic Radar Cross Section RCS, σ

$$\sigma_{pq} = \lim_{R\to\infty}\left[4\pi R^2 \frac{\left|E_p^s\right|^2}{\left|E_q^i\right|^2}\right]$$

Power!

R → ∞ ←→ plane wave excitation in free space!

Objects on the ground ←→ plane wave?

No!

Image theory does not help !

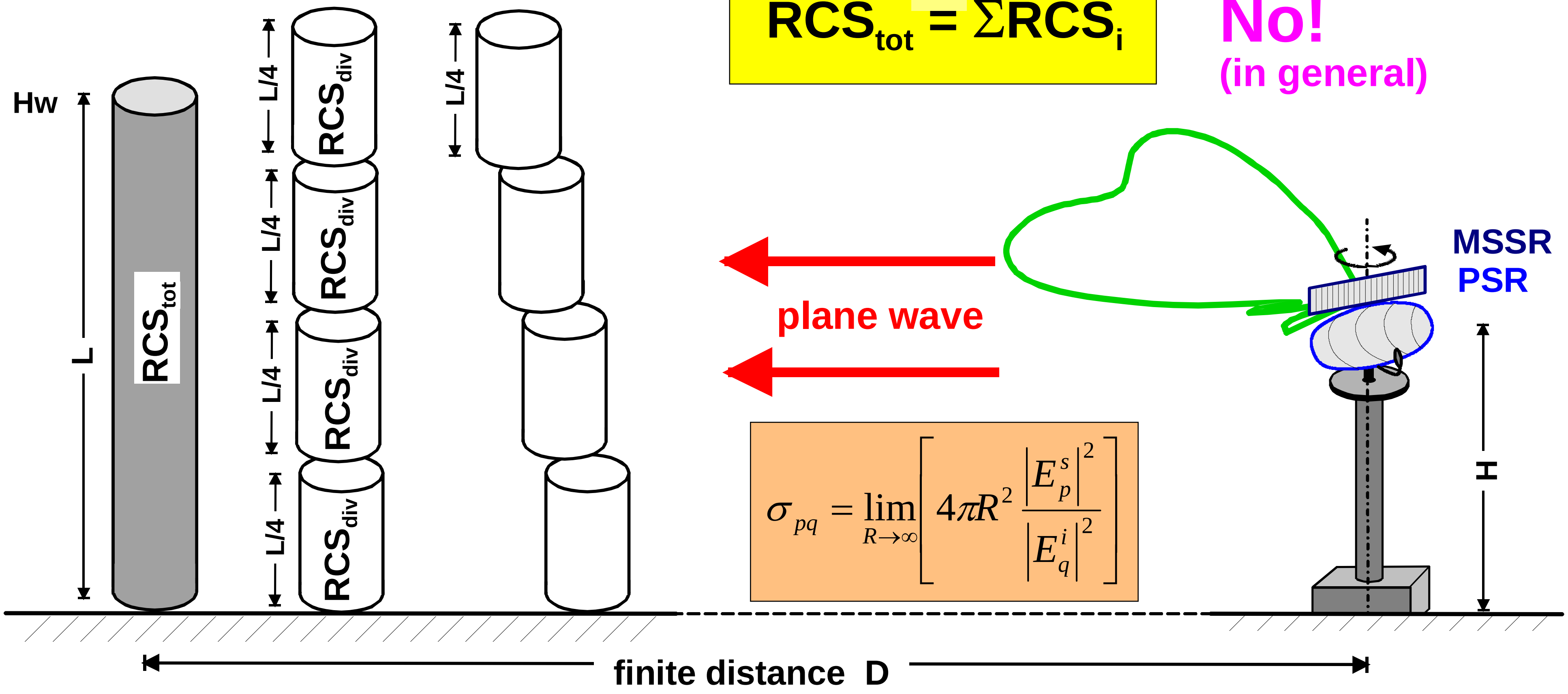
RCS and sub-division of object

$RCS_{tot} \geqslant 16\ RCS_{div}$

$> 4\ RCS_{div}$

$RCS_{tot} \overset{?!}{=} \Sigma RCS_i$

No!
(in general)



$$\sigma_{pq} = \lim_{R \to \infty} \left[4\pi R^2 \frac{\left|E_p^s\right|^2}{\left|E_q^i\right|^2} \right]$$

Scattering behavior is quite different !

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rcs_cyl_sect1.dsf 03/07

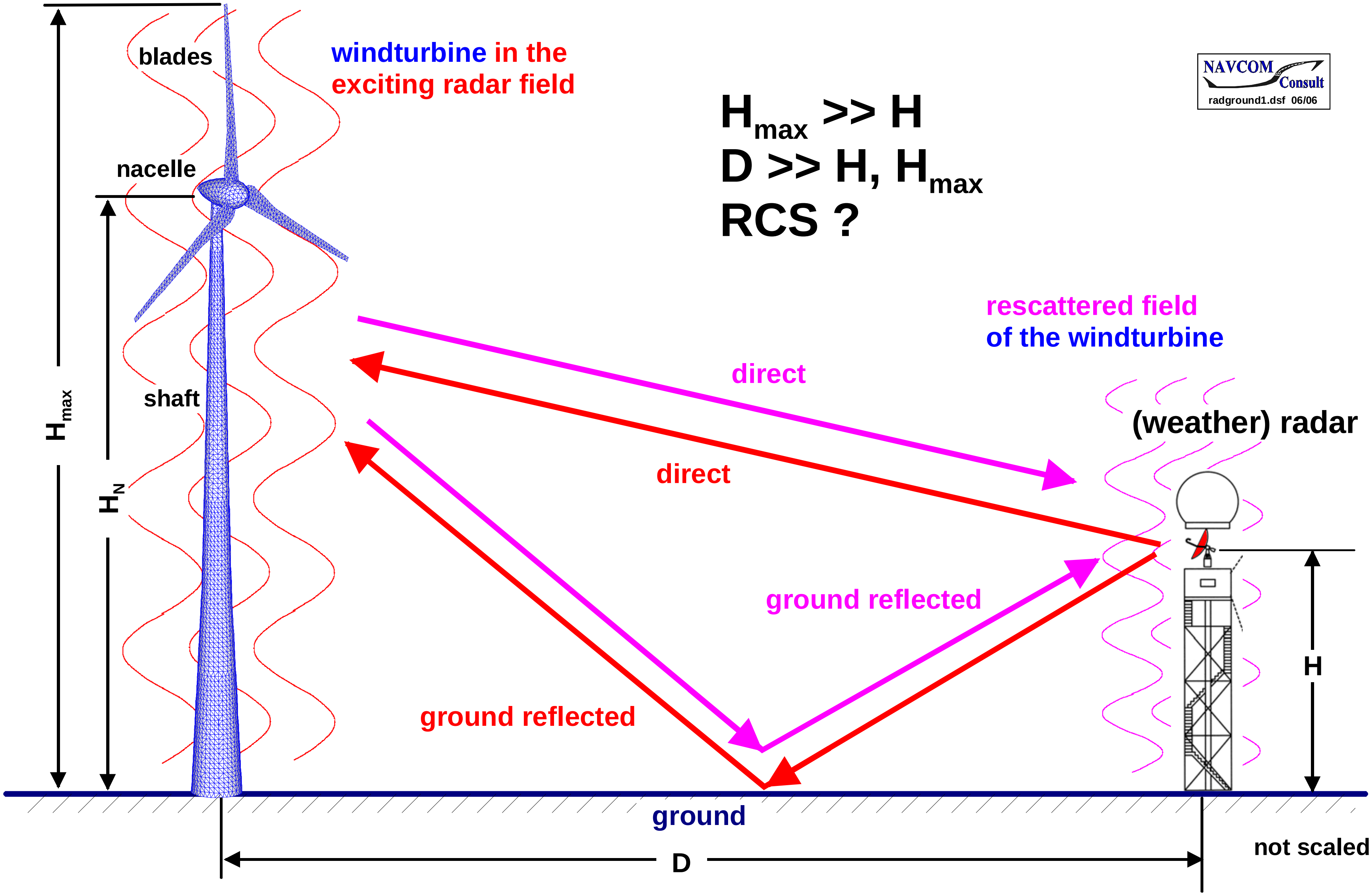

Image theory does not help !

⇨ **RCS of windturbines - Weather Radar**

RCS strictly speaking possible ? ←→ no plane waves

Which condition is applicable for a "characteristic RCS"?

"worst case" (worst, worst case) physically ?

⇨ **RCS / Scattering fields - Specifics of windturbines**

RCS (scattered field) is mono-frequent in case of no wind

RCS (scattered field) has a Doppler spectrum in case of wind

Rotating blade tips may have a speed of up to 300km/h

Doppler spectrum is always symmetrical (0Hz, ±Hz)

Windturbines can be identified uniquely ←→ coexistence possible

- **known position**
- **symmetrical Doppler spectrum**

Summary RCS :

RCS strictly speaking not applicable to wind turbines

Error unknown; site and scenario dependant

Measurements of RCS of windturbines also not relevant

⇨ NAVCOM Consult does not work with RCS !

See numerical results below

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Modeling and Simulations / Predictions

Reliable simulations offer answers in advance!

Measurements not possible!

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Modeling and Simulations

- ⇨ **Modeling for geometrical requirements ←→ 2D, 3D**
- ⇨ **Modeling for electrical requirements ←→ currents**
  - → **Modeling and subdivision into triangular metallic patches (IPO, MLFMM)**
  - → **linear segments for lightning arrestor**
- ⇨ **Modeling for system specifics**
- ⇨ **Numerical calculation → Simulation**

  Reflections, Diffraction, Scattering

  Numerical Methods
- ⇨ **As accurate needed / possible**
- ⇨ **State of the art procedure / approach**
- ⇨ **Never simulate "field fluctuations"**

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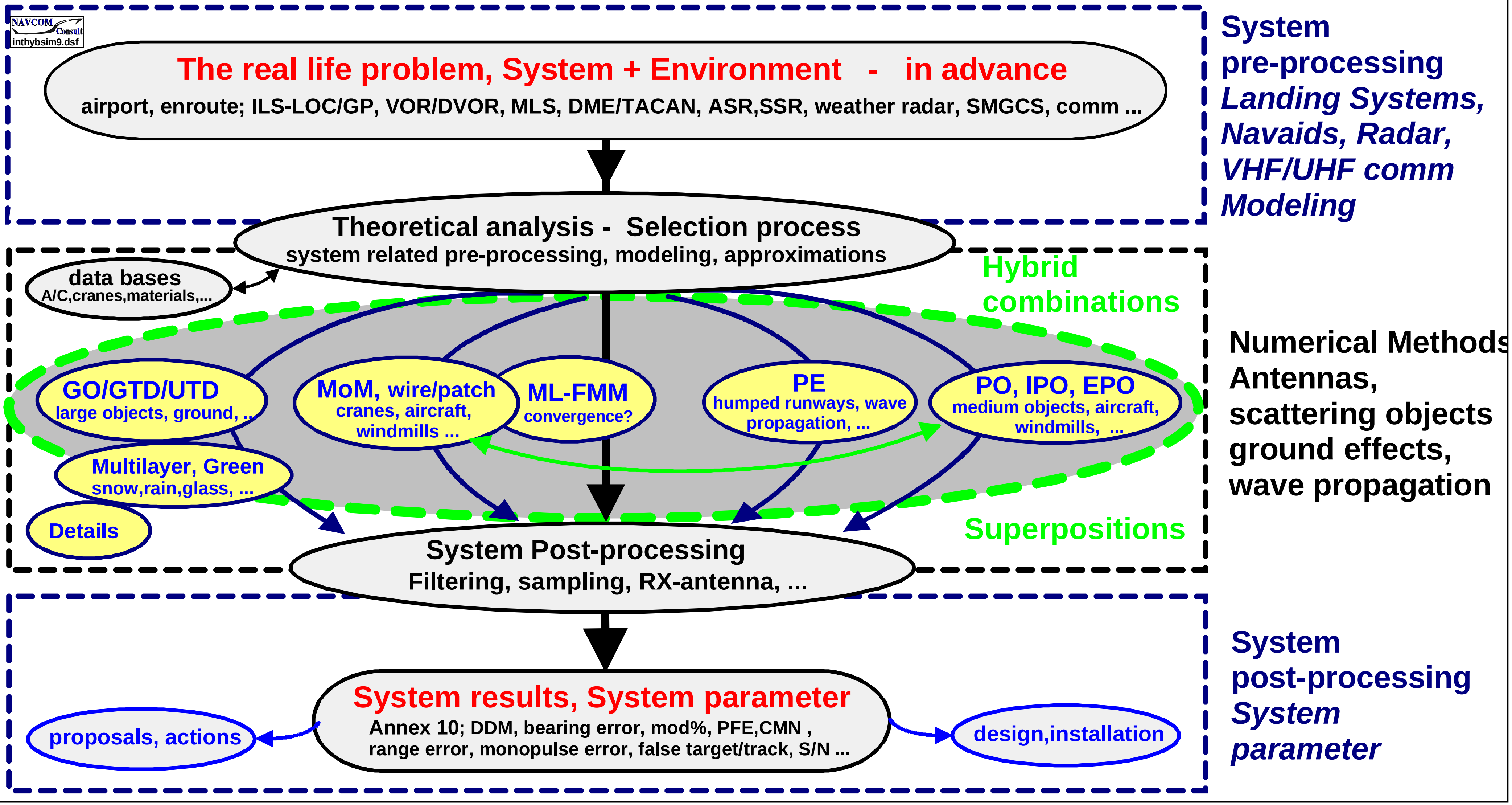
Numerical System Simulations IHSS
An integrated hybrid system approach

inthybsim9dsf 11/06



Systems and Wind Turbines
Examples

⇨ **DVOR** **bearing error for rotating blades**
Doppler spectrum for rotating blades

⇨ **S-band radar Doppler spectrum for rotating blades**

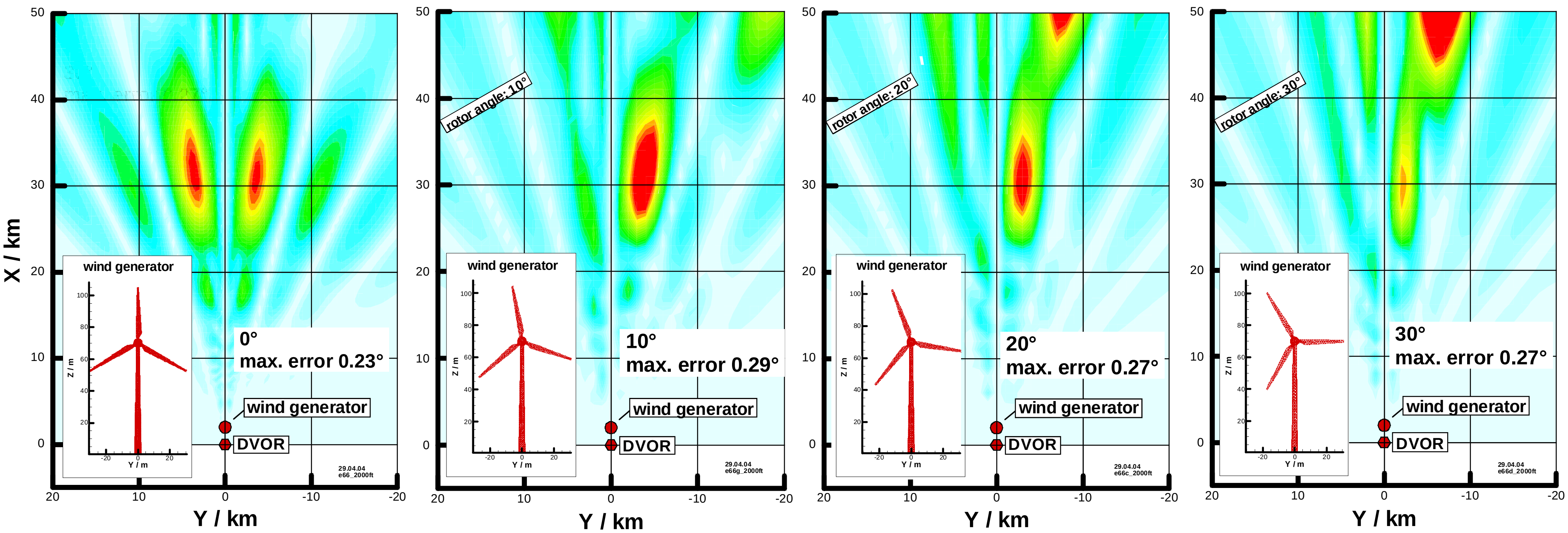
⇨ **S-band radar “shadowing” in the back**
(distance of WT and object , azimuth, elevation)

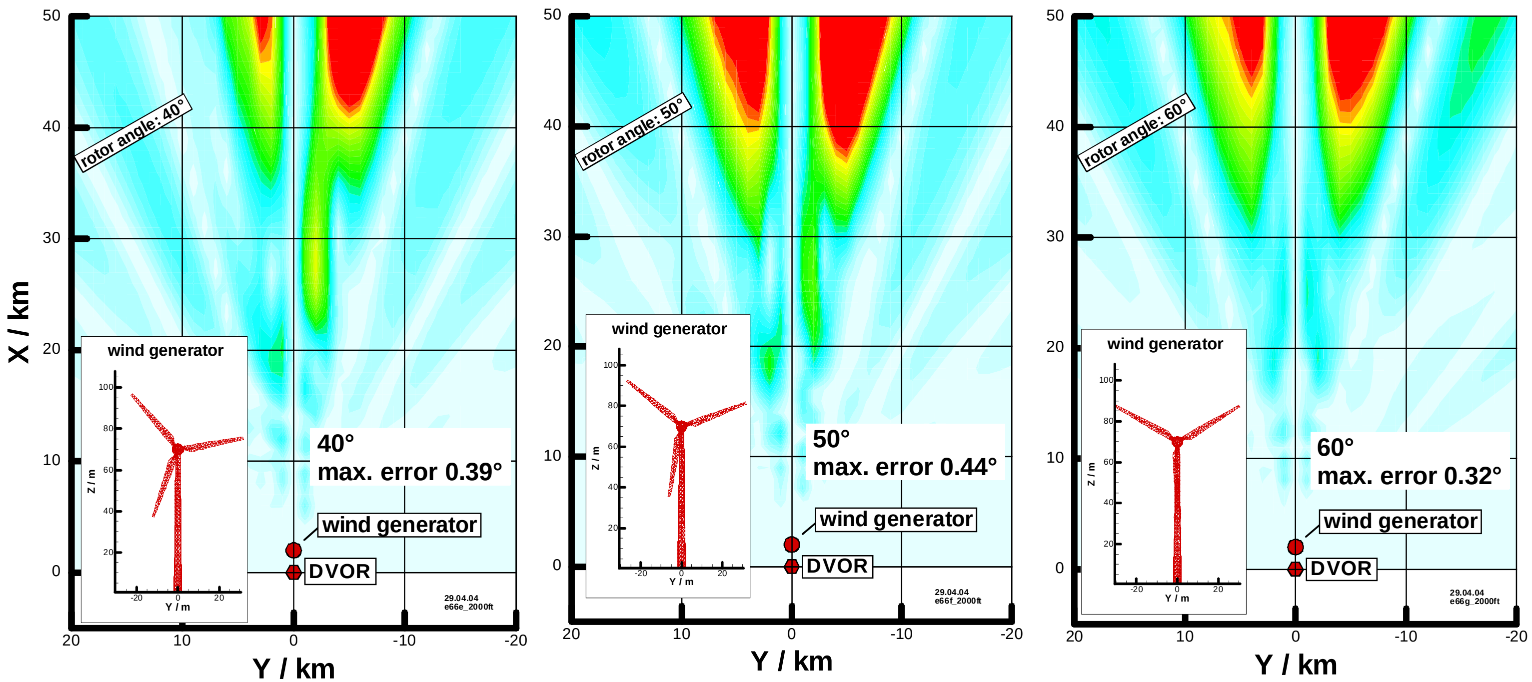
⇨ **SSR/MSSR** **interrogation fieldstrength 2D**
Monopulse angle error

⇨ **RCS of a wind turbine at S-band**
Scattering simulations of sphere and windturbines

⇨ **DVOR bearing error for rotating blades**

Doppler spectrum for rotating blades





DVOR bearing error as a function of the rotation angle

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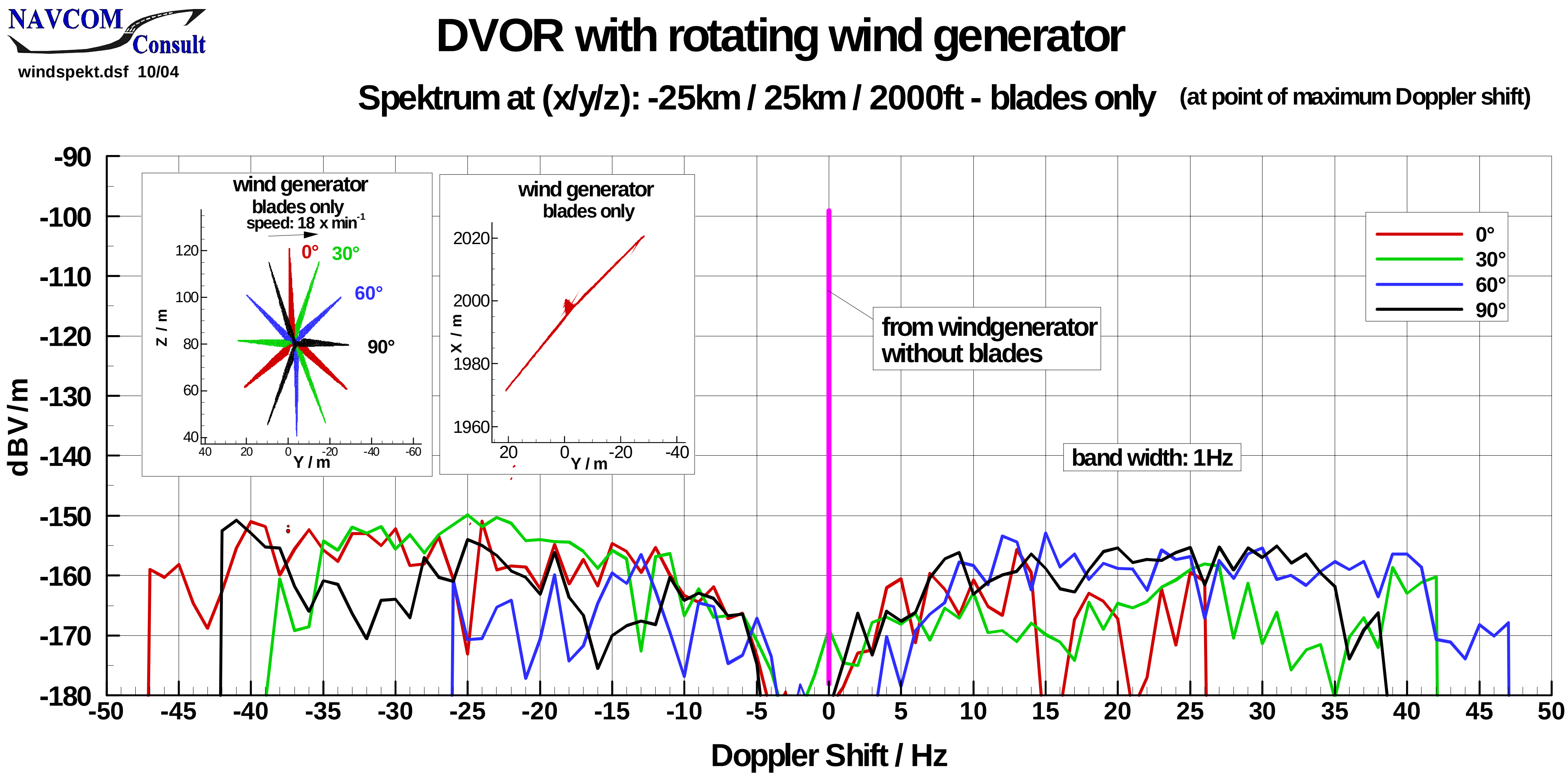
DVOR_e66_case4.dsf 04/04

DVOR reflector position (X/Y/Z): 0 / 0 / 4.4
wind generator at (X/Y): 2000m / 0m
hub height 70m, blade diam. 70m
azimuth rotation angle: 0°
angle of rotor blades: 0°..60°
flat terrain
frequency: 110 MHz
DVOR reflector diameter: 30m

DVOR - Doppler frequency spectrum by rotating blades



⇨ **S-band radar Doppler spectrum for windturbines and rotating blades**

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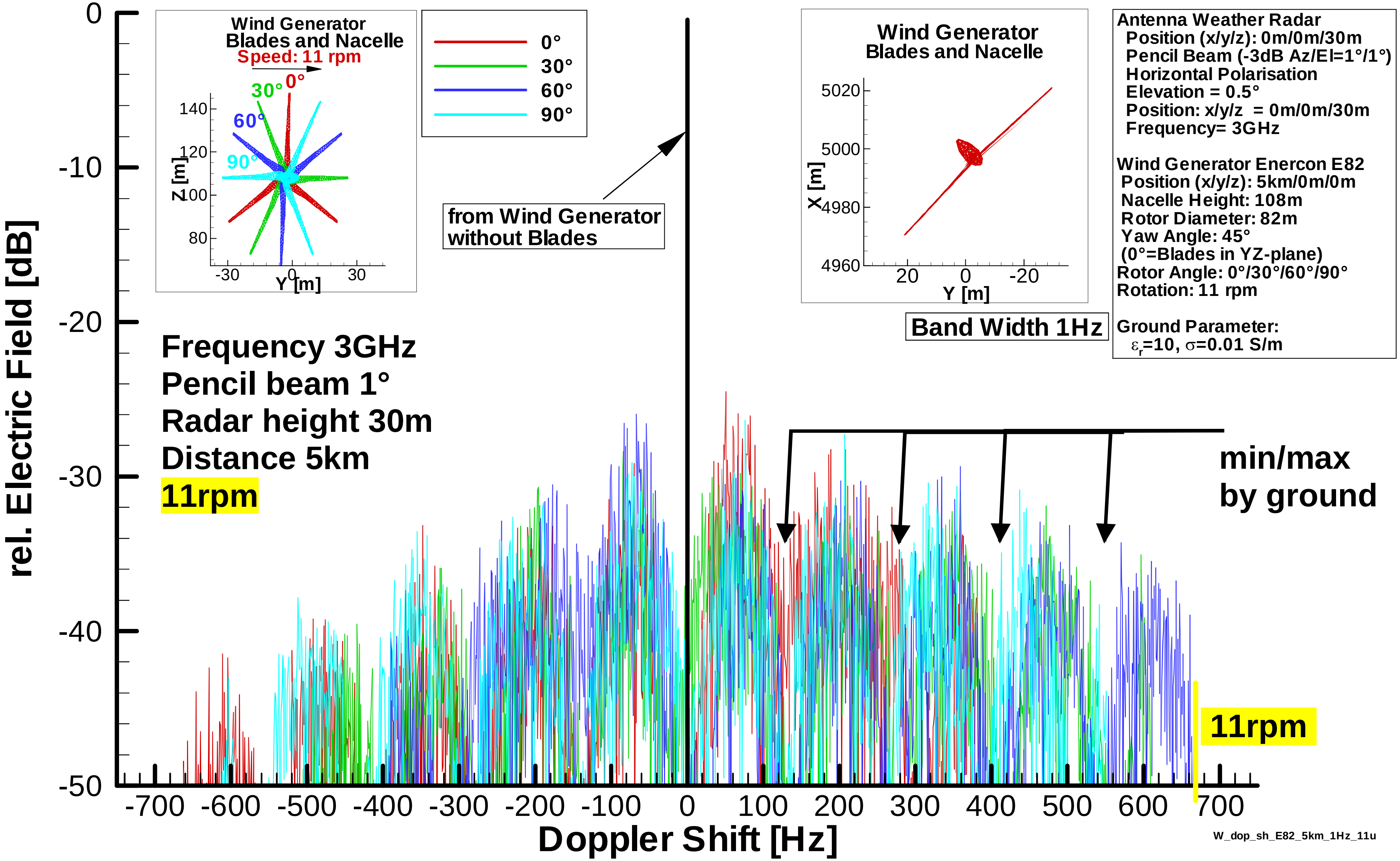
WTE82_doppl1.dsf 12/06

Doppler shift spectrum of back scattered signal WT E82

Spectrum at radar antenna position (monostatic)



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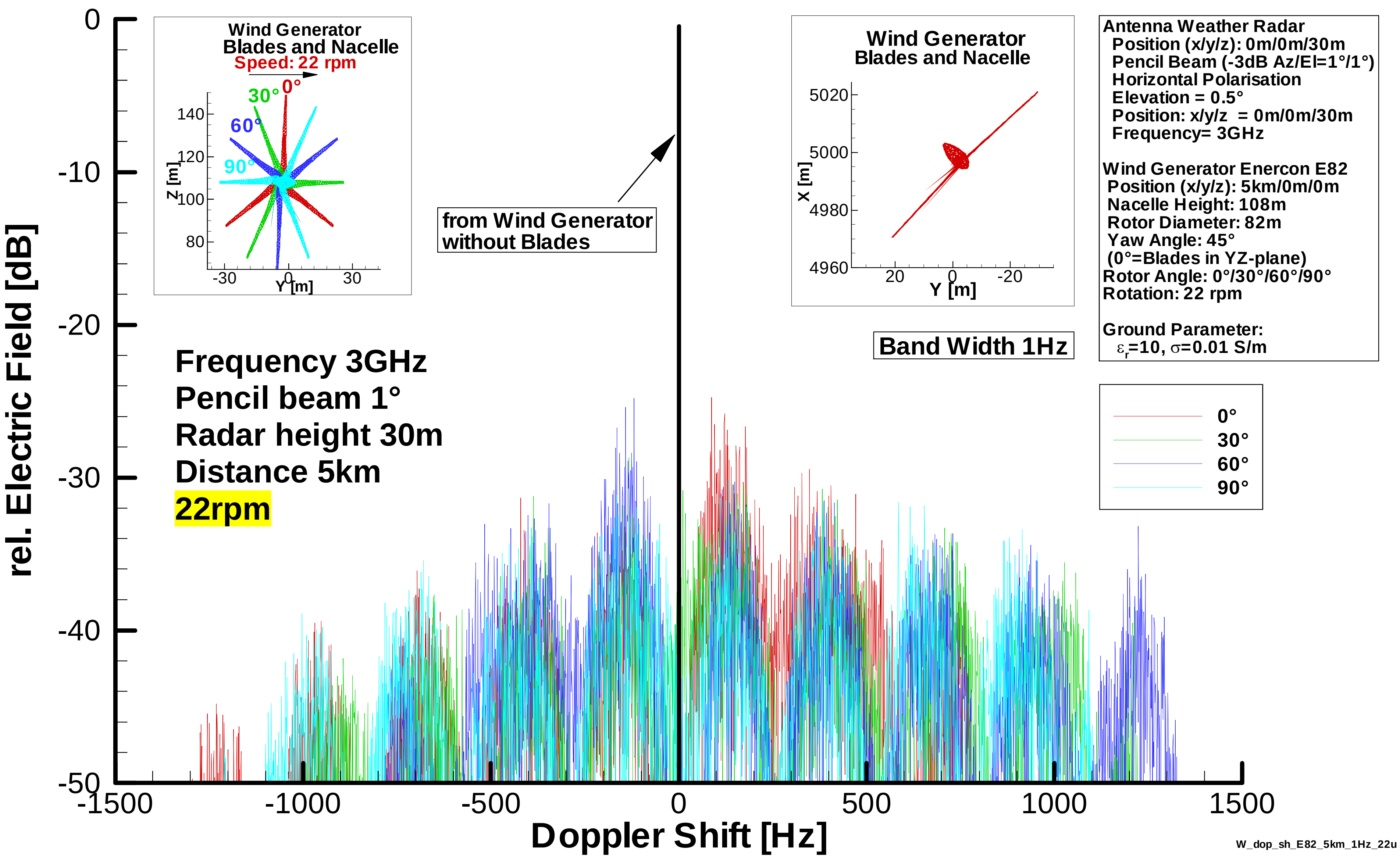
WTE82_doppl2.dsf 12/06

Doppler shift spectrum of back scattered signal WT E82

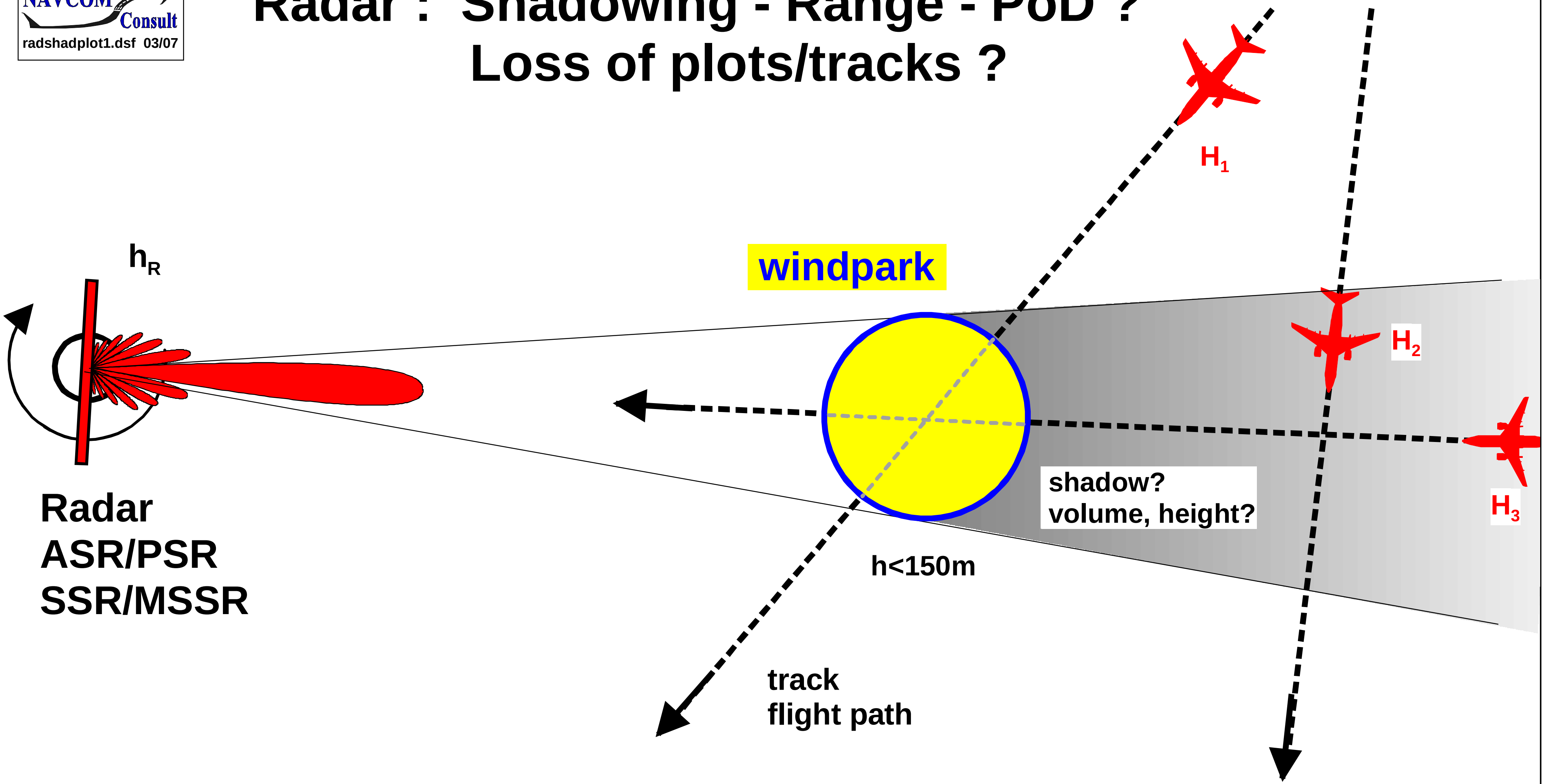
Spectrum at radar antenna position (monostatic)



⇨ **S-band radar shadowing in the back**

(distance, azimuth, elevation)

Radar : Shadowing - Range - PoD ? Loss of plots/tracks ?



Natural effects by environment to be considered

SSR/MSSR mostly no problems

PSR dependant on technology, height, definition/interpretation of PoD

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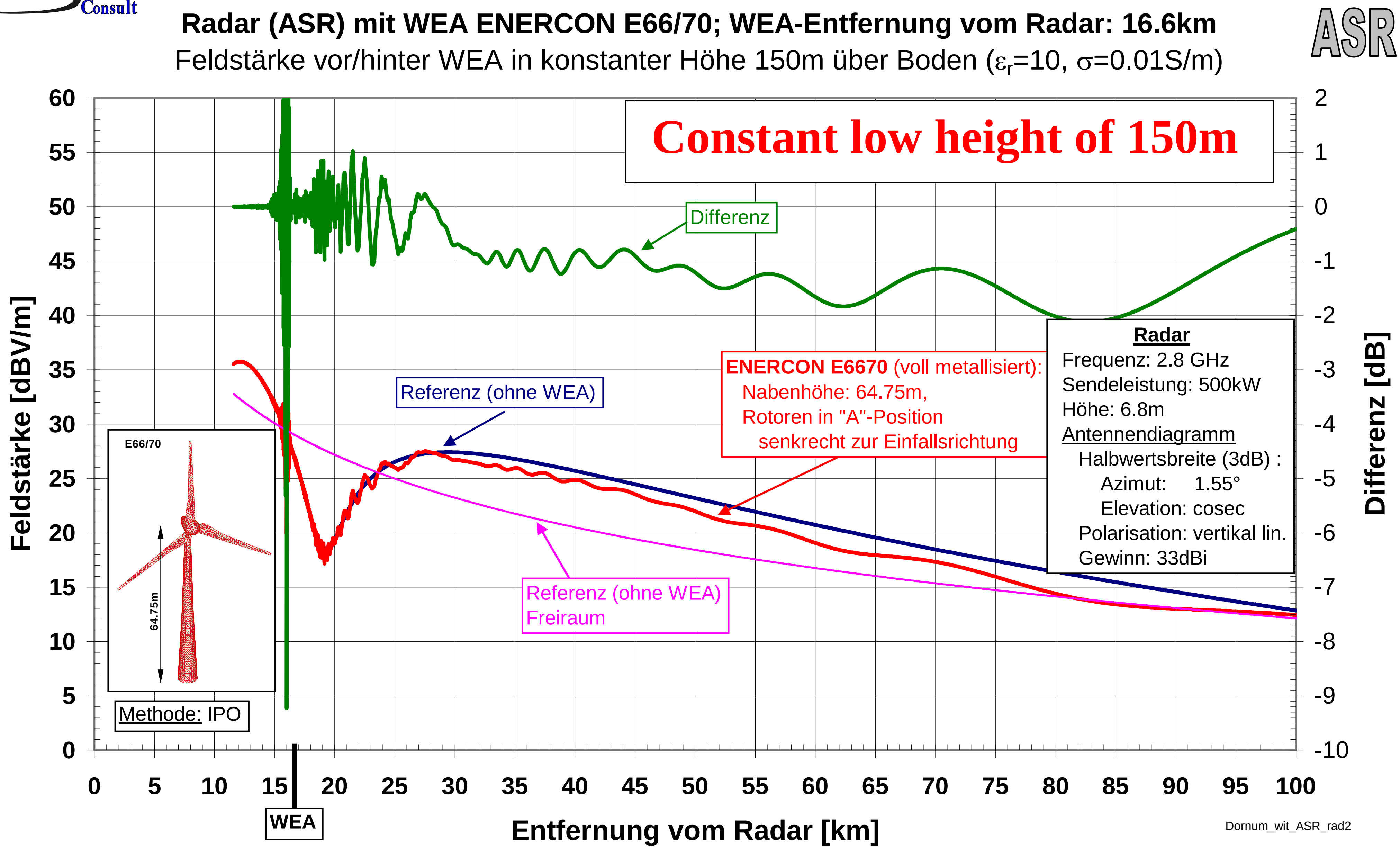
ASR



Loss/attenuation only in small volumes down at the ground ←→ PoD

- **EUROCONTROL : pragmatic approach**
  SUR.ET1.ST01.1000-STD-01-01
  SUR.ET1.ST03.1000-STD-01-01

- **Overall probability of detection measured**

$$\text{PoD} = \frac{\text{number of detected target reports}}{\text{number of expected target reports}}$$

- **PSR → 90%, SSR → 97%, combined 95%**

- **Small reductions in the back of wind turbines and “holes” above a windpark do not affect the overall PoD significantly**

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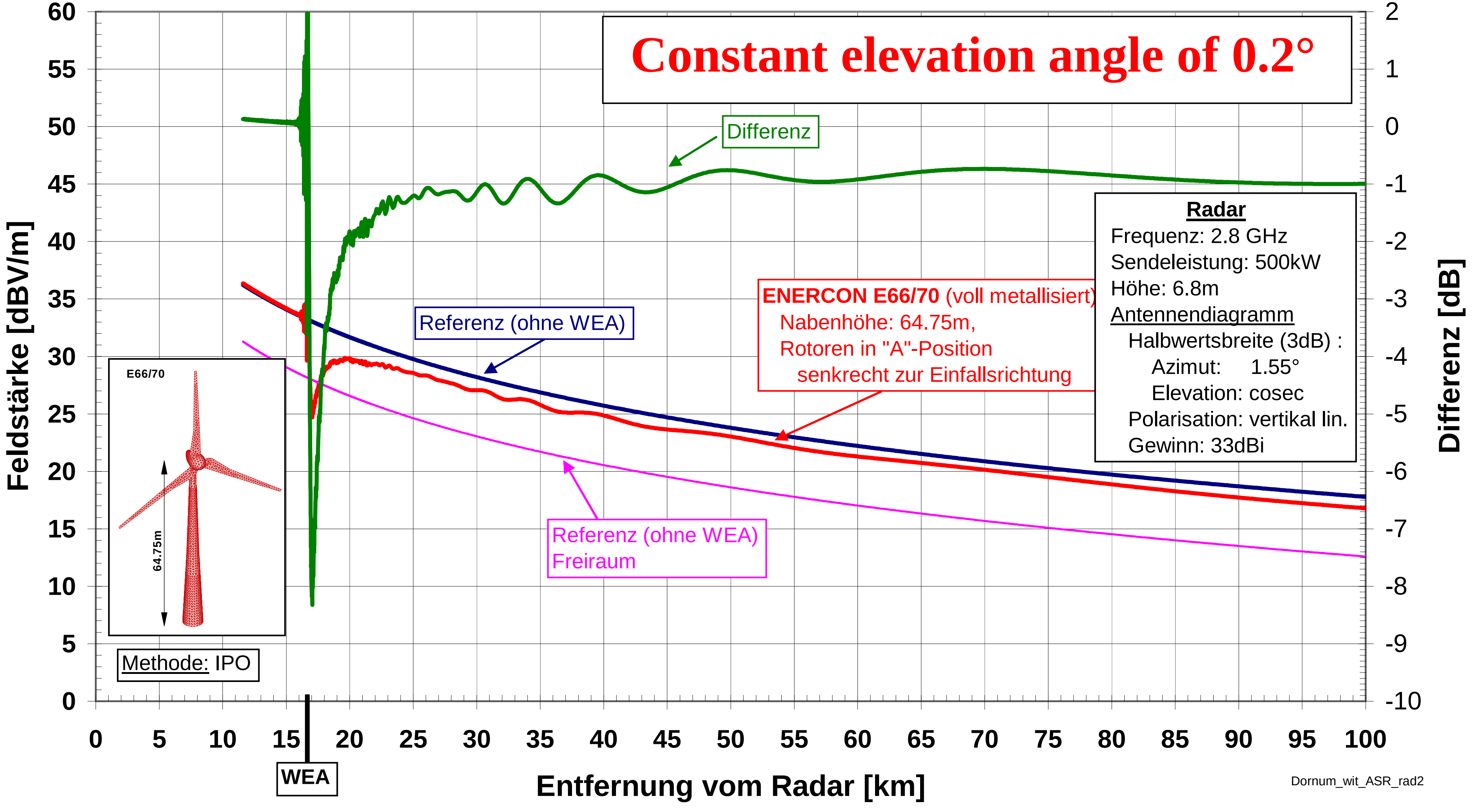
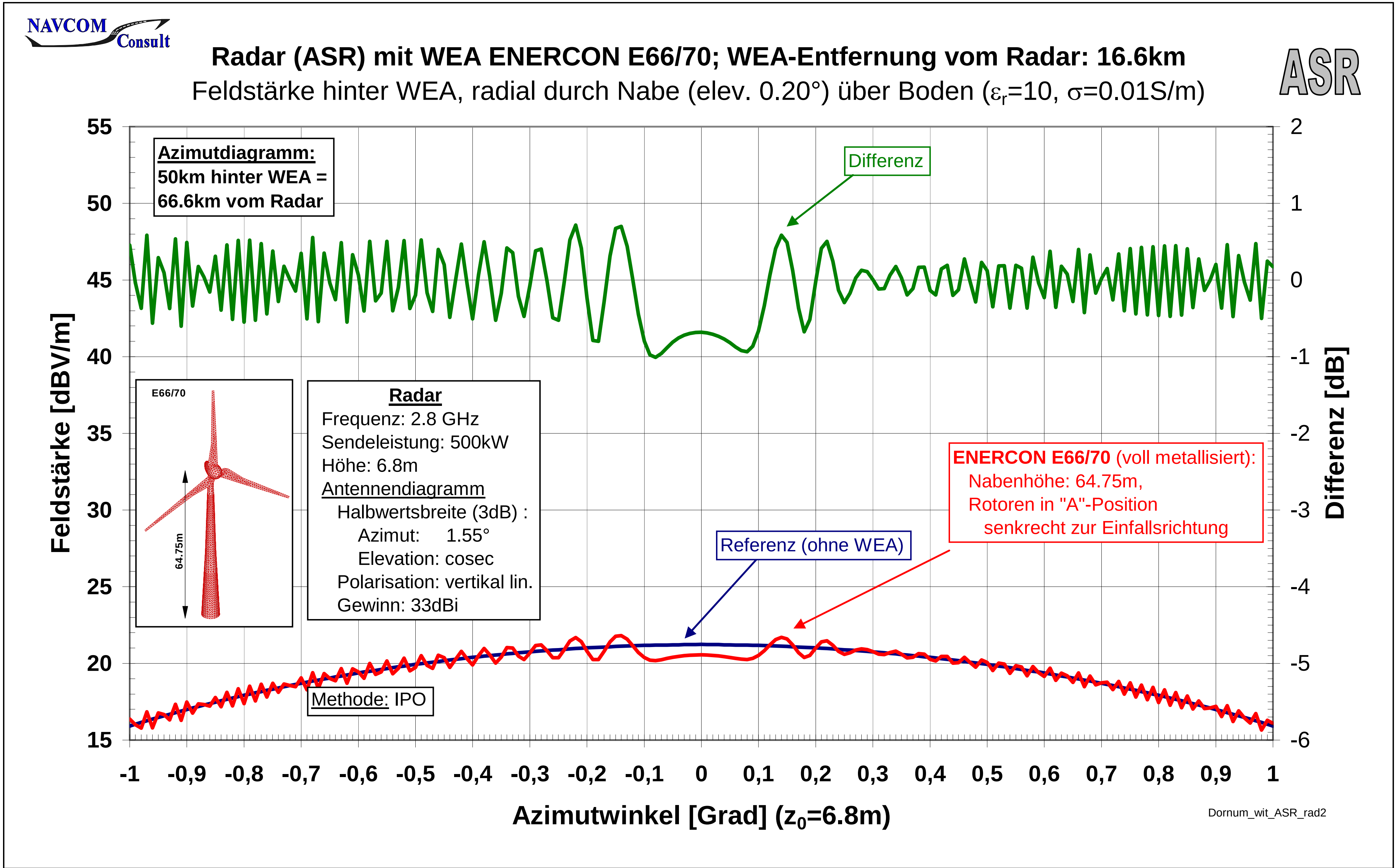
Radar (ASR) mit WEA ENERCON E66/70; WEA-Entfernung vom Radar: 16.6km

Feldstärke vor/hinter WEA, radial durch Nabe (elev. 0.20°) über Boden (ε_r=10, σ=0.01S/m)

ASR





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Radar (ASR) mit WEA ENERCON E66/70; WEA-Entfernung vom Radar: 16.6km
Feldstärke hinter WEA, radial durch Nabe (elev. 0.20°) über Boden (ε_r=10, σ=0.01S/m)
ASR
Azimutdiagramm:
50km hinter WEA =
66.6km vom Radar
Differenz
E66/70
64.75m
Radar
Frequenz: 2.8 GHz
Sendeleistung: 500kW
Höhe: 6.8m
Antennendiagramm
Halbwertsbreite (3dB) :
Azimut: 1.55°
Elevation: cosec
Polarisation: vertikal lin.
Gewinn: 33dBi
ENERCON E66/70 (voll metallisiert):
Nabenhöhe: 64.75m,
Rotoren in "A"-Position
senkrecht zur Einfallsrichtung
Referenz (ohne WEA)
Methode: IPO
Feldstärke [dBV/m]
Differenz [dB]
55
50
45
40
35
30
25
20
15
2
1
0
-1
-2
-3
-4
-5
-6
-1
-0,9
-0,8
-0,7
-0,6
-0,5
-0,4
-0,3
-0,2
-0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
Azimutwinkel [Grad] (z_0=6.8m)
Dornum_wit_ASR_rad2

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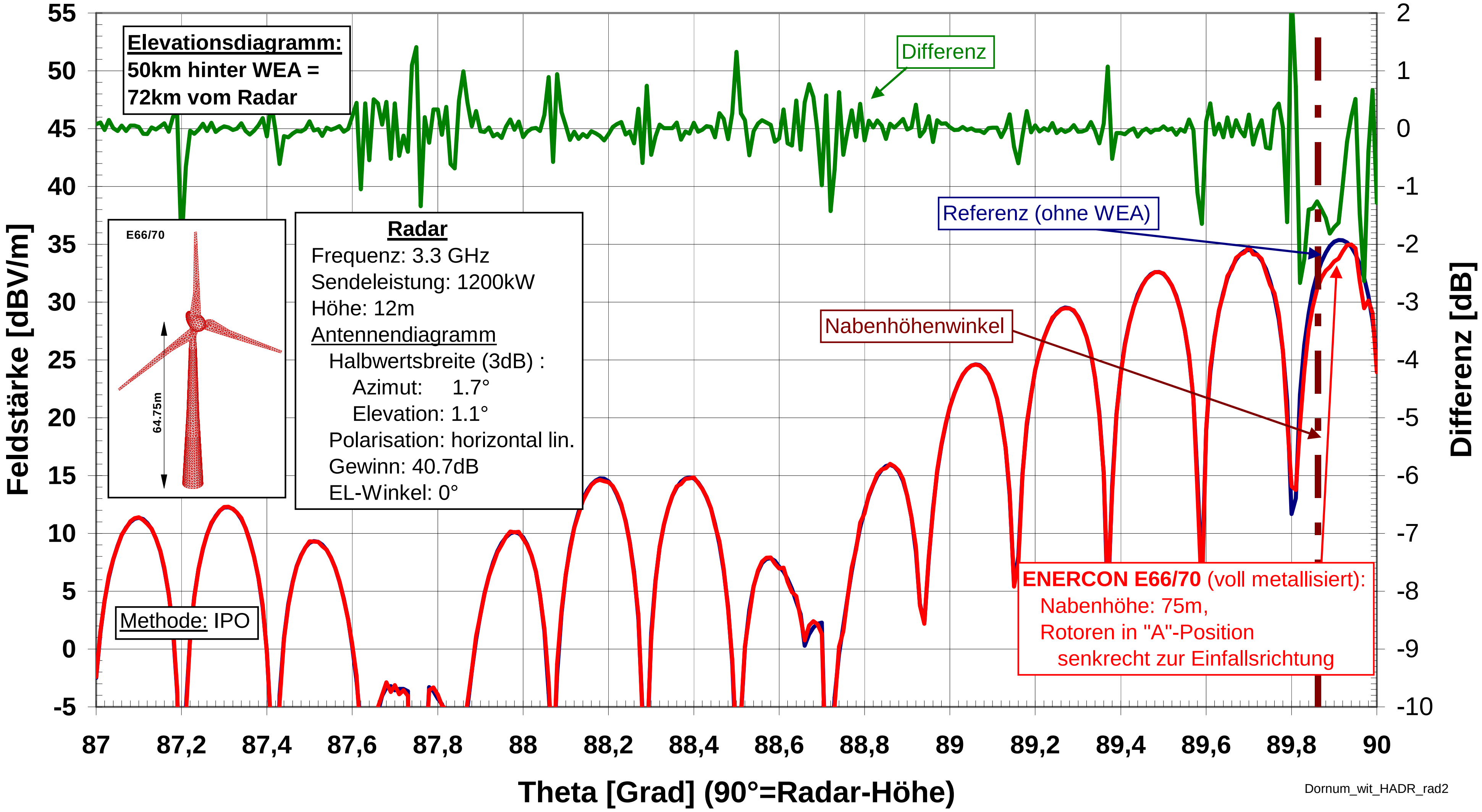
Radar (HADR) mit WEA ENERCON E66/70; WEA-Entfernung vom Radar: 22km

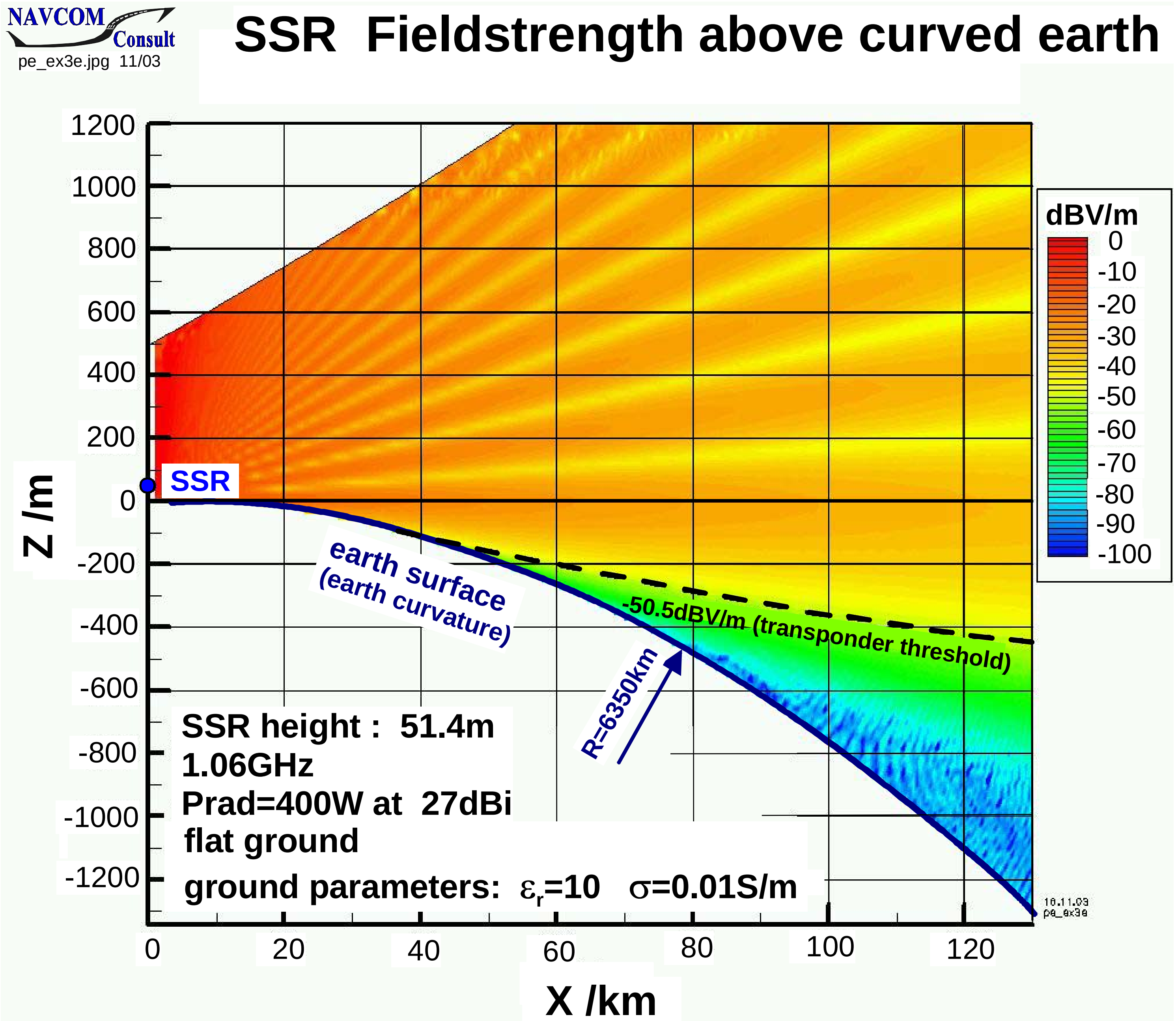
Feldstärke hinter WEA, Elevationsdiagramm über Boden (ε_r=10, σ=0.01S/m)

HADR



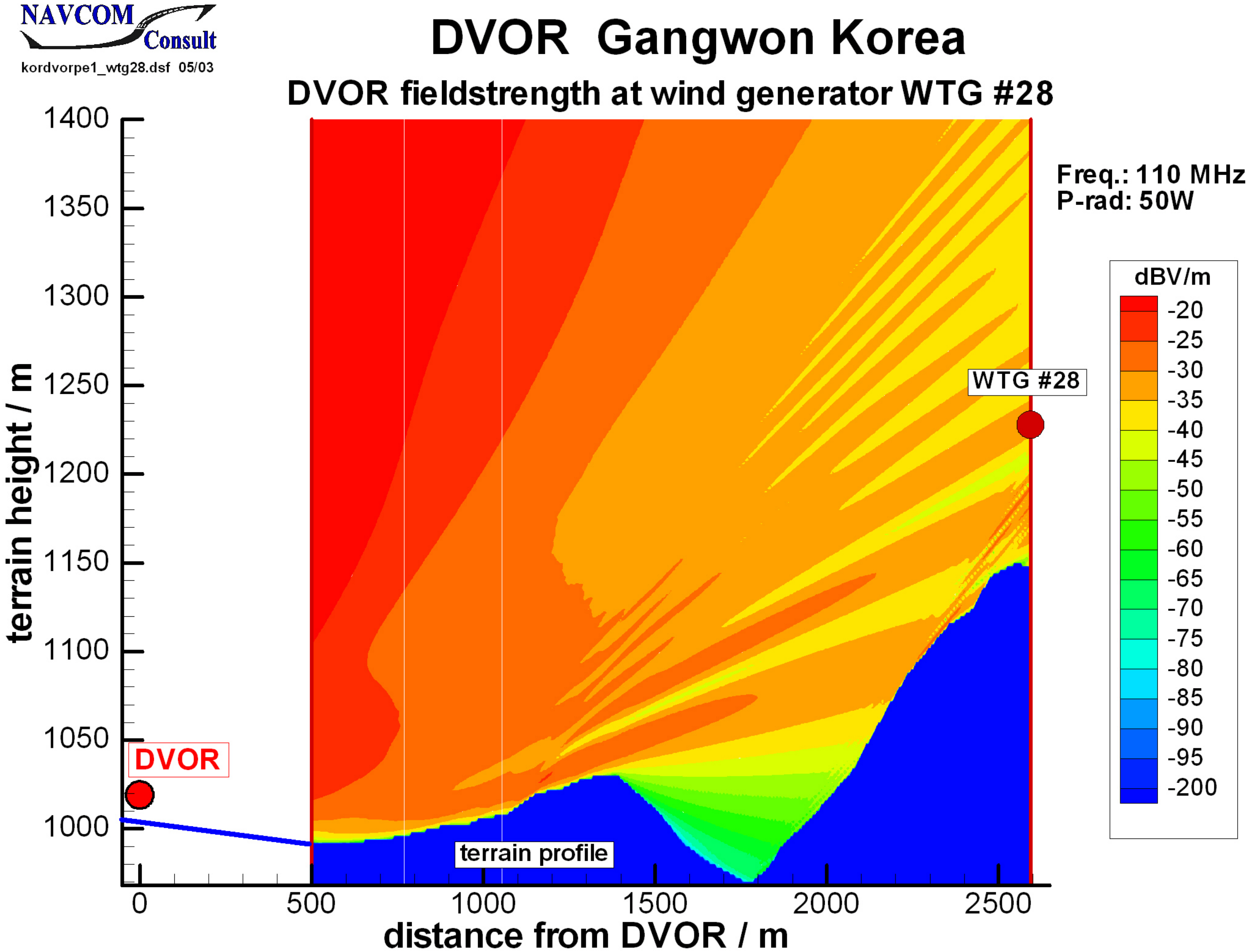
Vertical lobing of elevation pattern ; natural phenomenon by ground
Windturbine negligible

SSR Fieldstrength above curved earth



DVOR Gangwon Korea

DVOR fieldstrength at wind generator WTG #28



⇨ **SSR/MSSR** **interrogation fieldstrength 2D**

No interrogation <-71dBm Mode S

<-68dBm Mode A/C

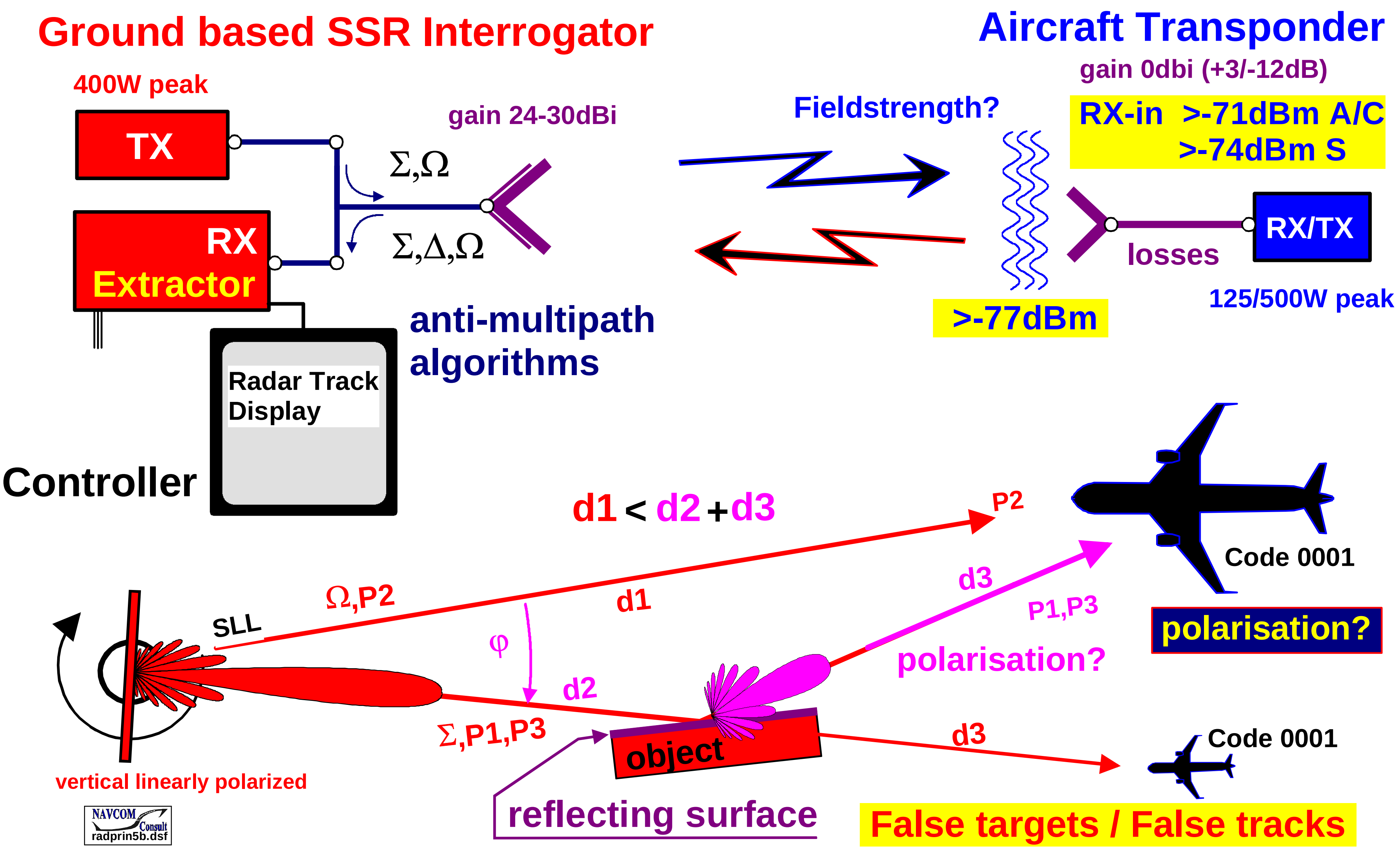
Monopulse angle error <0.08° rms

?

Monopulse ratio Σ, Δ

MR = f(k,Δ,Σ,Φ**)**

SSR/MSSR and Multipath



Scattering from objects and SSR
False interrogations (1)

⇨ **Scattering ←→ reflection**
Diffraction
creeping waves
…

⇨ **Scattered field > MTL (Minimum Triggering Level) ?**

→ **reduction of scattering by xdB**

Methods on system level excluded

⇨ **Methods to reduce scattering (…) necessary**

Scattering from objects and SSR
False interrogations (2)

⇨ **Methods:** **Absorption (absorber) → transfer to heat**

~~Interference absorber~~

Lossy structures

Reduction of scattering gain

~~Periodic structures~~

Random structures

Re-dicrection to other directions ("stealth")

~~ATC-radar have 360° coverage, SSR bistatic~~

Towards lossy and rough ground (Brewster effect/angle)

scattering fences on flat roofs

~~Re-direction to orthogonal polarization~~

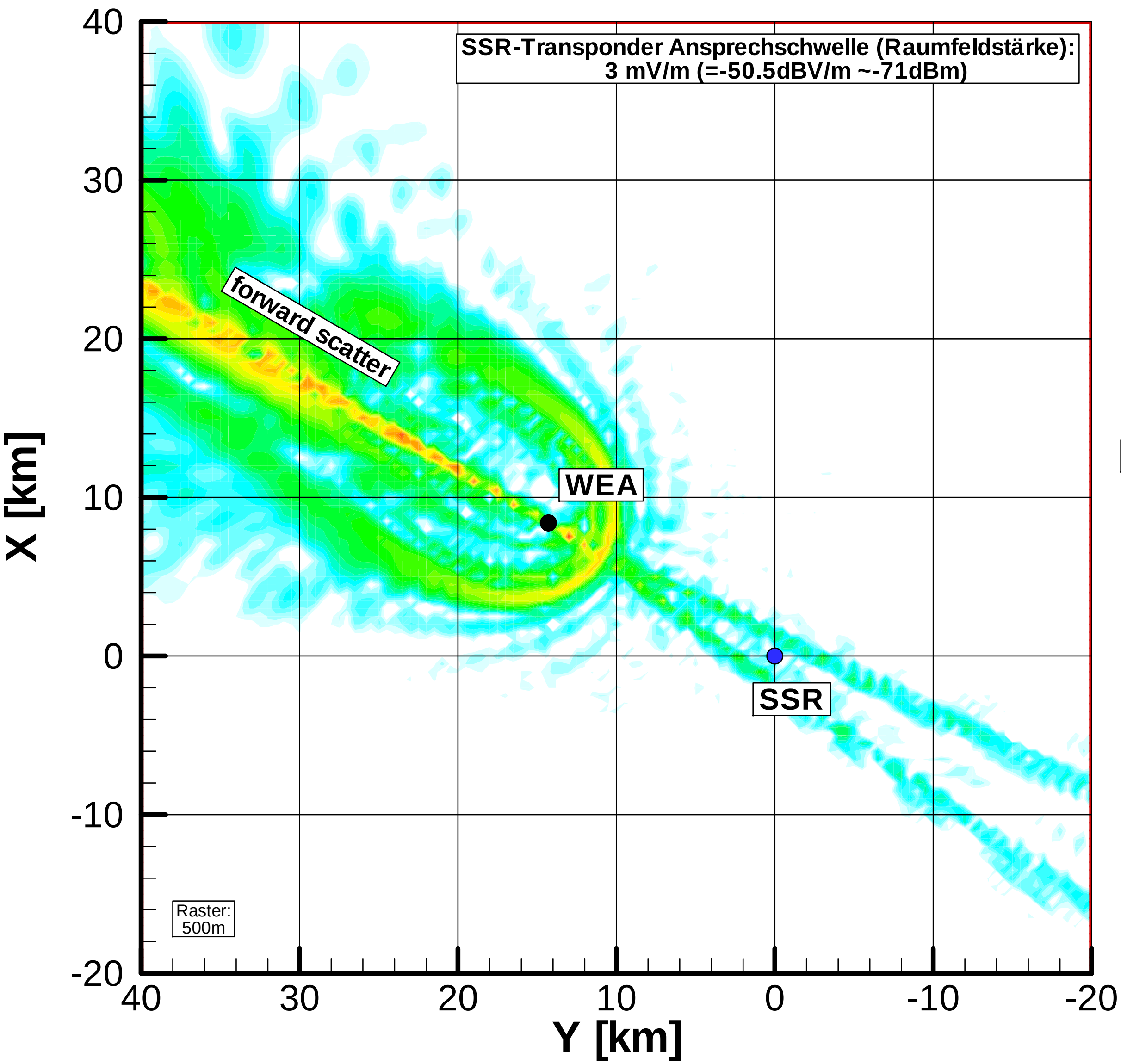
No absorption, polarizer not acceptable for ATC

Dornum_SSR_Witt_wea30_1kftb

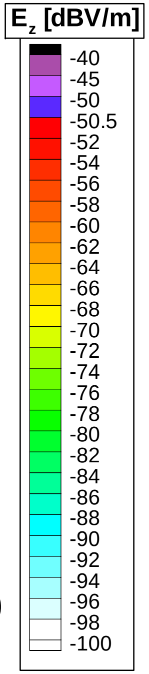
SSR (IFF) Wittmundhafen

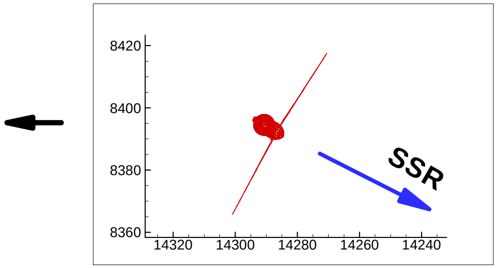
Windpark Dornum - WEA30 (ϕ=0°, β=0°)

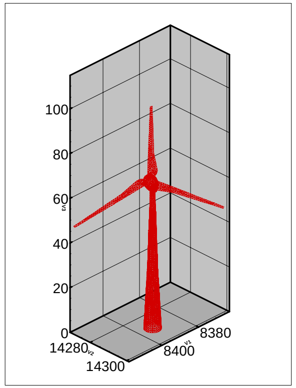
Streufeldstärke in 1000ft (304.8m) Höhe



SSR:
X / Y / Z= 0 / 0 / 8.6 [m]
Sendeleistung: 84W bei 19dBi
im Maximum des SSR-Diagramms
Halbwertsbreite AZ 4°, EL 60°
(low aperture)
WEA ENERCON E66/70:
X / Y = 8395 / 14291 [m]
Distanz / Winkel = 16574m / 59.6°
Nabenhöhe: 64.75m
Rotordurchmesser: 70m
lokale Rotation ϕ: 0°= senkrecht SSR
aktuelle Rotation ϕ : 0°
Blattrotation β: 0° (0°= 1 Bl. senkr.)
Blattverdrehung: 0°
Boden: ε_r =10, σ =0.01 S/m



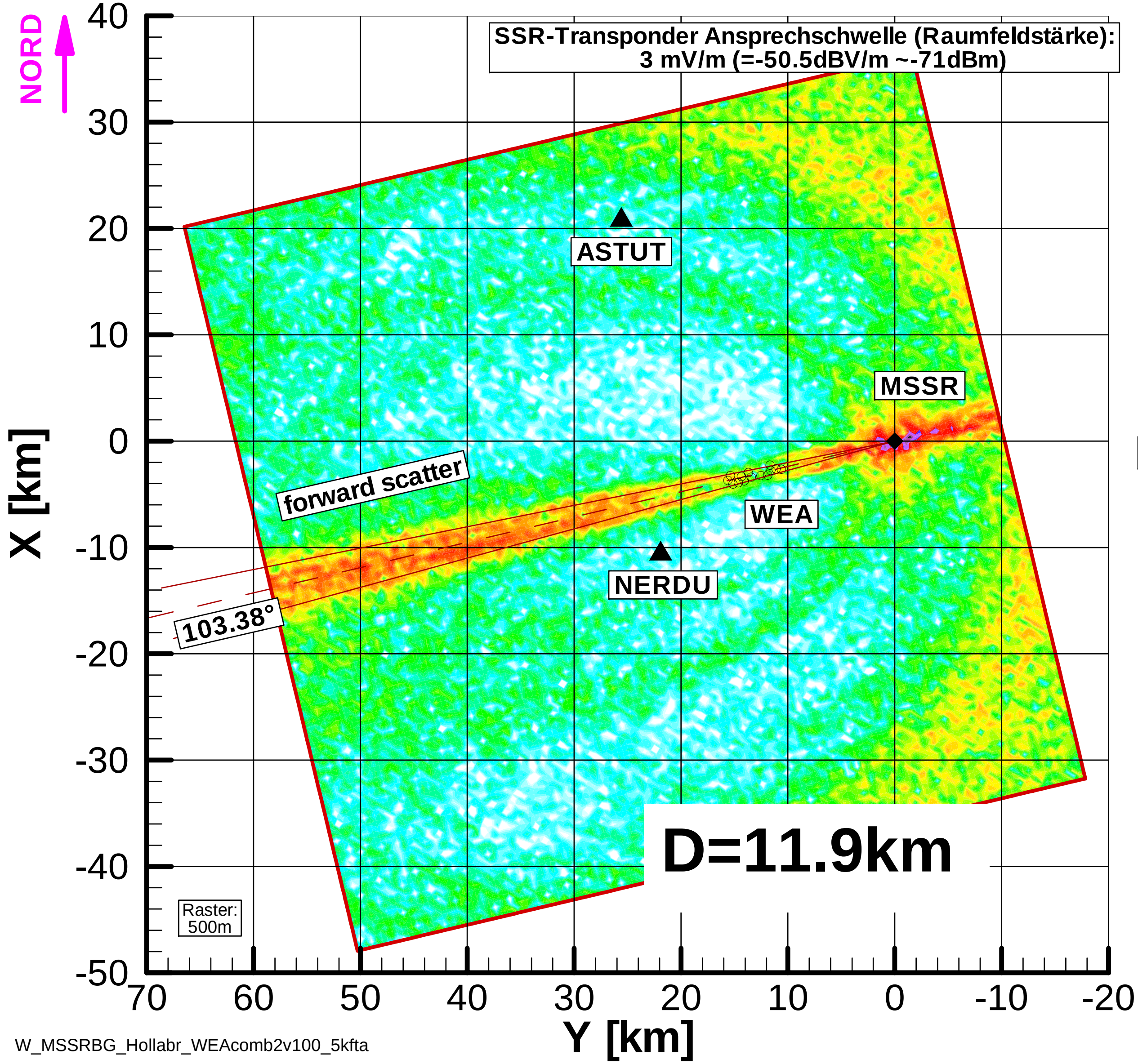




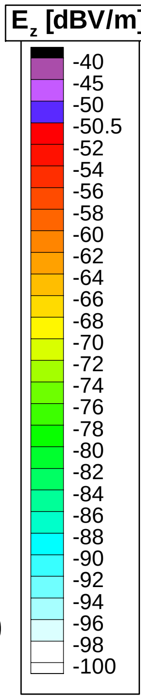
MSSR Buschberg (W_MSSRBG)

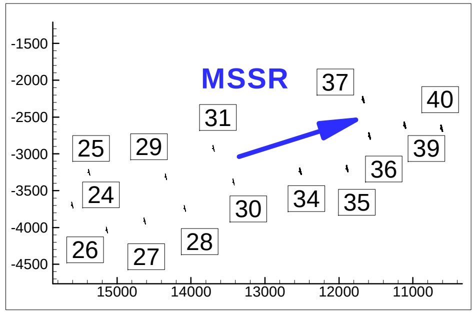
Windpark "Hollabrunn" - WEA 24 - 31, 34 - 37, 39, 40 (ϕ=0°, β=0°)

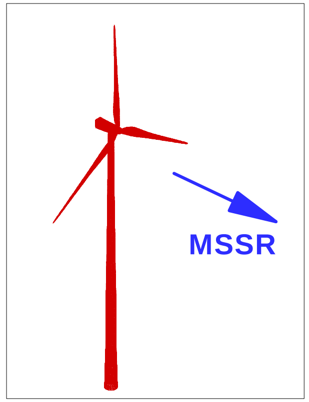
Streufeldstärke in 5000ft (1524m) Höhe (MSL); 3868 ft (1179m) über Boden



MSSR:
X / Y / Z= 0 / 0 / 33 [m] / 103.38° (WEA36)
Sendeleistung: 800W bei 24dBi
im Maximum des SSR-Diagramms
Halbwertsbreite AZ 2.36°
WEA VESTAS V100 2.75MW:
X / Y = ... / ... [m]
Distanz / Winkel = ...m / ...°
Nabenhöhe: 125m
Rotordurchmesser: 100m
lokale Rotation ϕ: 0°= senkrecht SSR
aktuelle Rotation ϕ : parallel WEA36
Blattrotation β: 0° (0°= 1 Bl. senkr.)
Blattverdrehung: 0° (0°=senkr. zum MSSR)
Boden: ε_r =10, σ =0.01 S/m





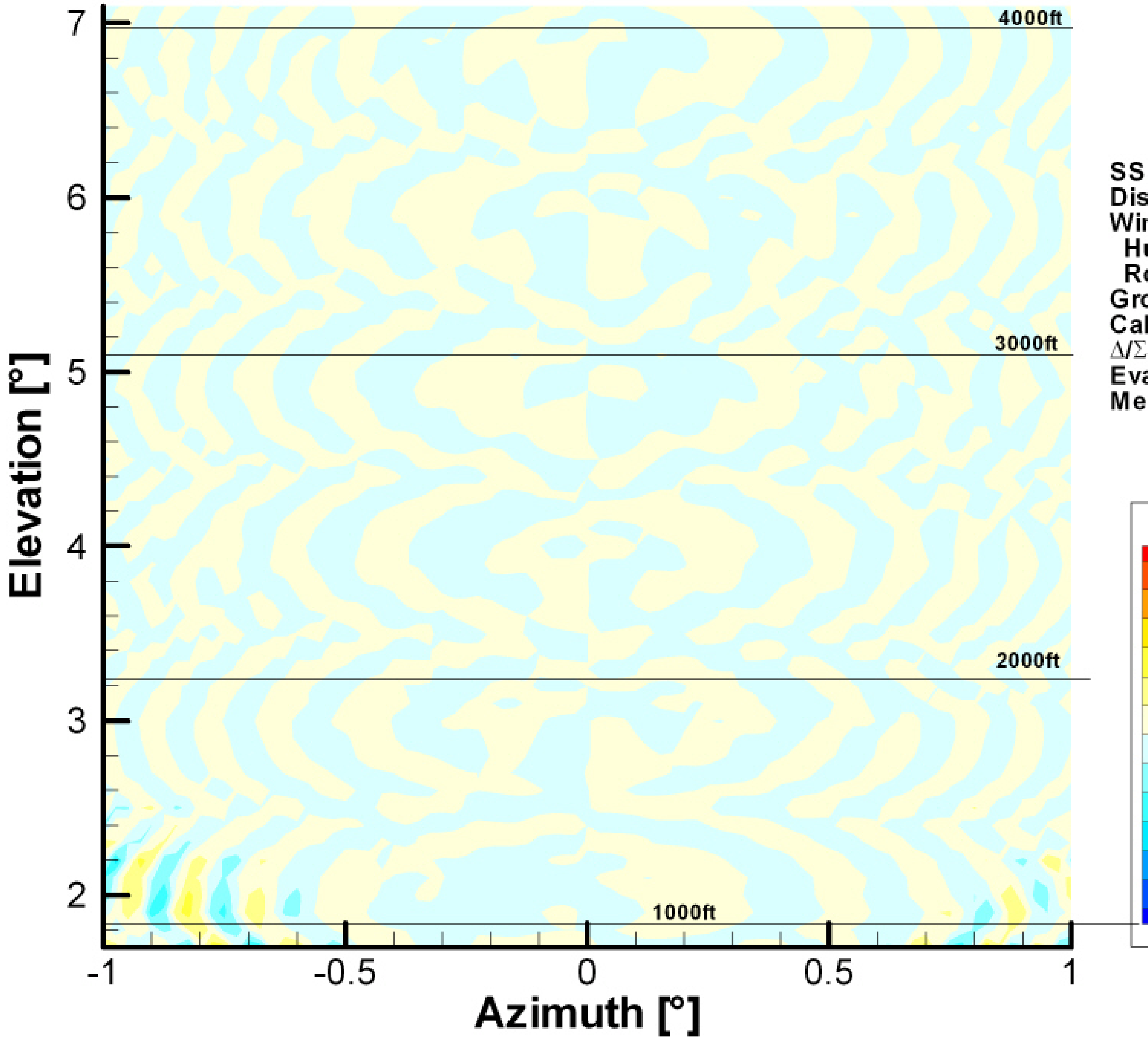


mssr_wt_angleerror1.dsf 12/06

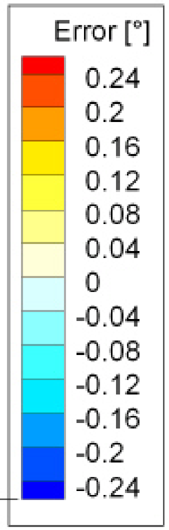
Monopulse Angle Error by Windturbine E82

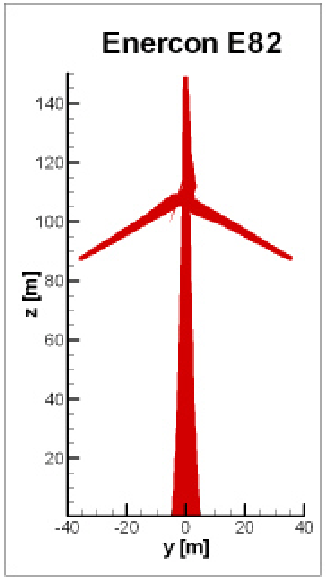
MSSR-antenna pointing on windturbine

Distance SSR-WT : 5km
Calcul: 10km



SSR Antenna (0/0/30m)
Distance SSR-Windgenerator: 5km
Windgenerator: Enercon E82
Hub height: 108m
Rotor diameter: 82m
Ground parameter: ε_r: 10, σ: 0.01 S/m
Calculation distance from SSR: 10km
Δ/Σ = -2dB
Evaluation with r-Phi Characteristic
Method: IPO





EC_SSR_10km_w0_AzF_2D

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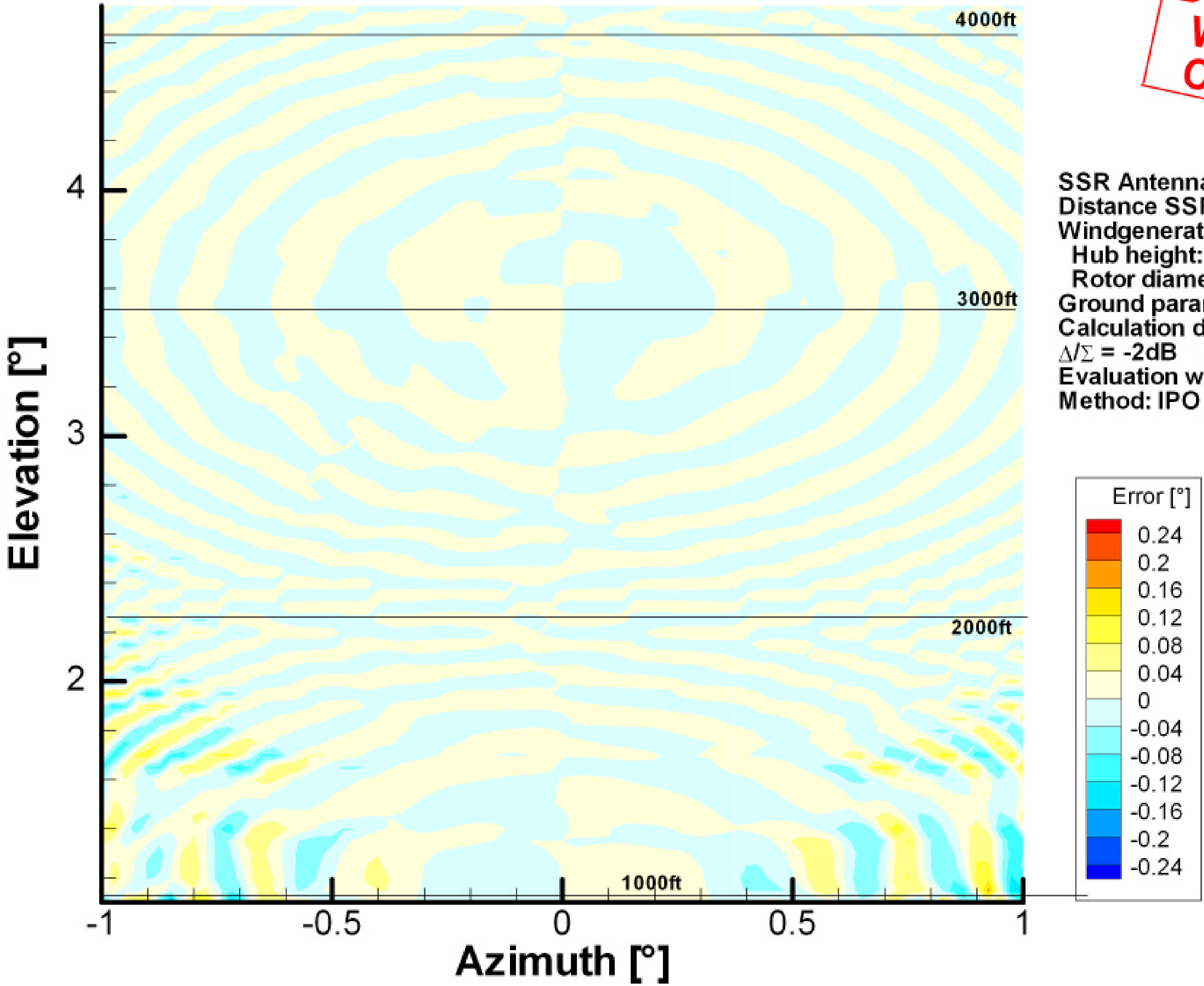
mssr_wt_angleerror2.dsf 12/06

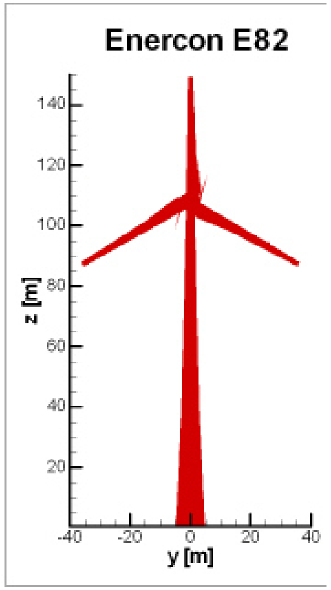
Monopulse Angle Error by Windturbine E82

MSSR-antenna pointing on windturbine

Distance SSR-WT : 5km
Calcul: 15km

SSR Antenna (0/0/30m)
Distance SSR-Windgenerator: 5km
Windgenerator: Enercon E82
Hub height: 108m
Rotor diameter: 82m
Ground parameter: ε_r: 10, σ: 0.01 S/m
Calculation distance from SSR: 15km
Δ/Σ = -2dB
Evaluation with r-Phi Characteristic
Method: IPO



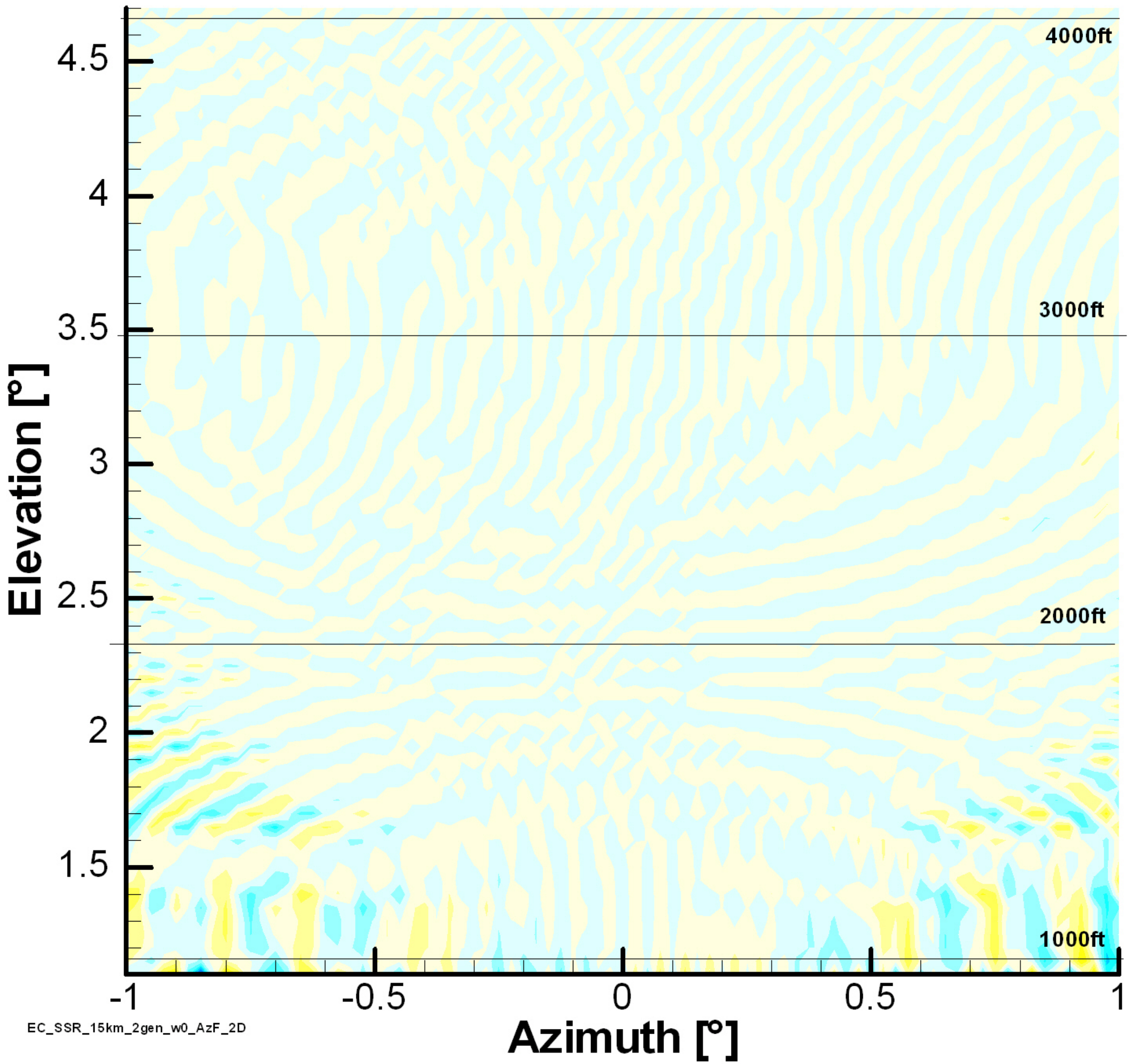


EC_SSR_15km_w0_AzF_2D

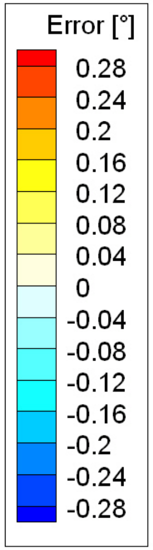
Monopulse Angle Error by 2 WT E82

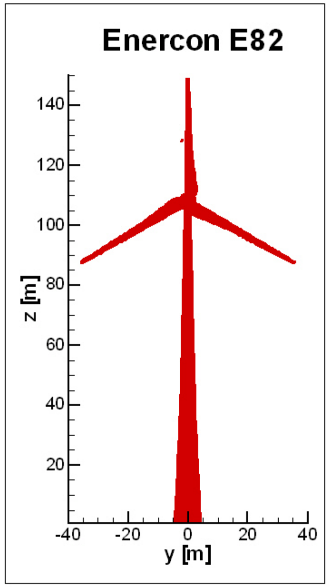
MSSR-antenna pointing on WT1

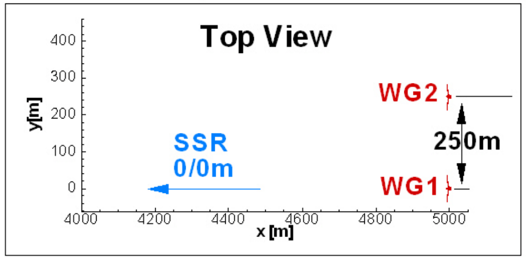
Distance SSR-2 WT: 5km
Calcul. : 15km



SSR Antenna (0/0/30m)
Position:
1. Windgenerator: 5000/0/0m
2. Windgenerator: 5000/250/0m
Windgenerator: Enercon E82
Hub height: 108m
Rotor diameter: 82m
Ground parameter: ε_r: 10, σ: 0.01 S/m
Calculation distance from SSR: 15km
Evaluation with r-Phi Characteristic
Δ/Σ = -2dB
Method: IPO





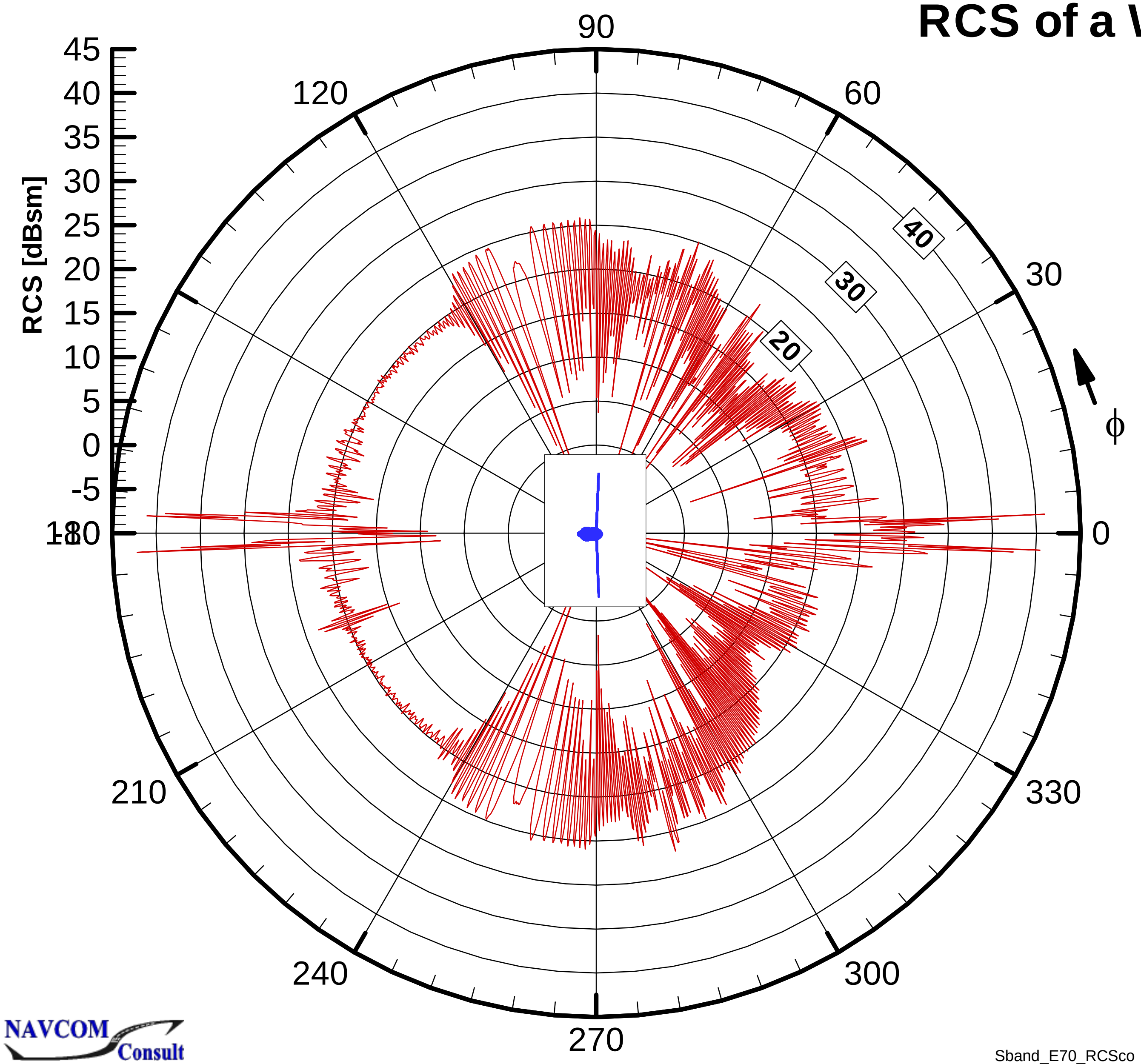


Numerical results for RCS and fields at wind turbines

- ⇨ RCS of a wind turbine at S-band
  Scattering simulations of sphere and windturbines
- ⇨ RCS of a wind turbine at S/C-band
  Frequency bands of ATC, military and Meteo-radar
- ⇨ exciting field strength by radar at wind turbine

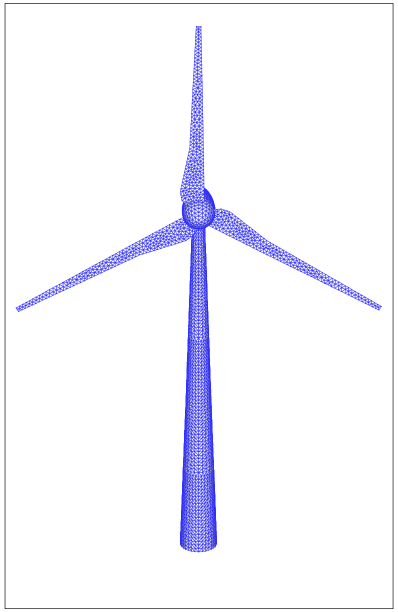
RCS is a 3D-function in free space → azimuth

RCS of a Wind Turbine (E70)



frequency: 3GHz (S-band)
Plane Wave:
polarization: horizontal (φ)
RCS: co-polar
Calculation Method: IPO

Enercon E70
nacelle height: 65m
blade diameter: 70m
blade pitch: 0°
tower diam. b/t: 6.1m/2m
blade rotation: 0° ("A")
yaw angle: 0°



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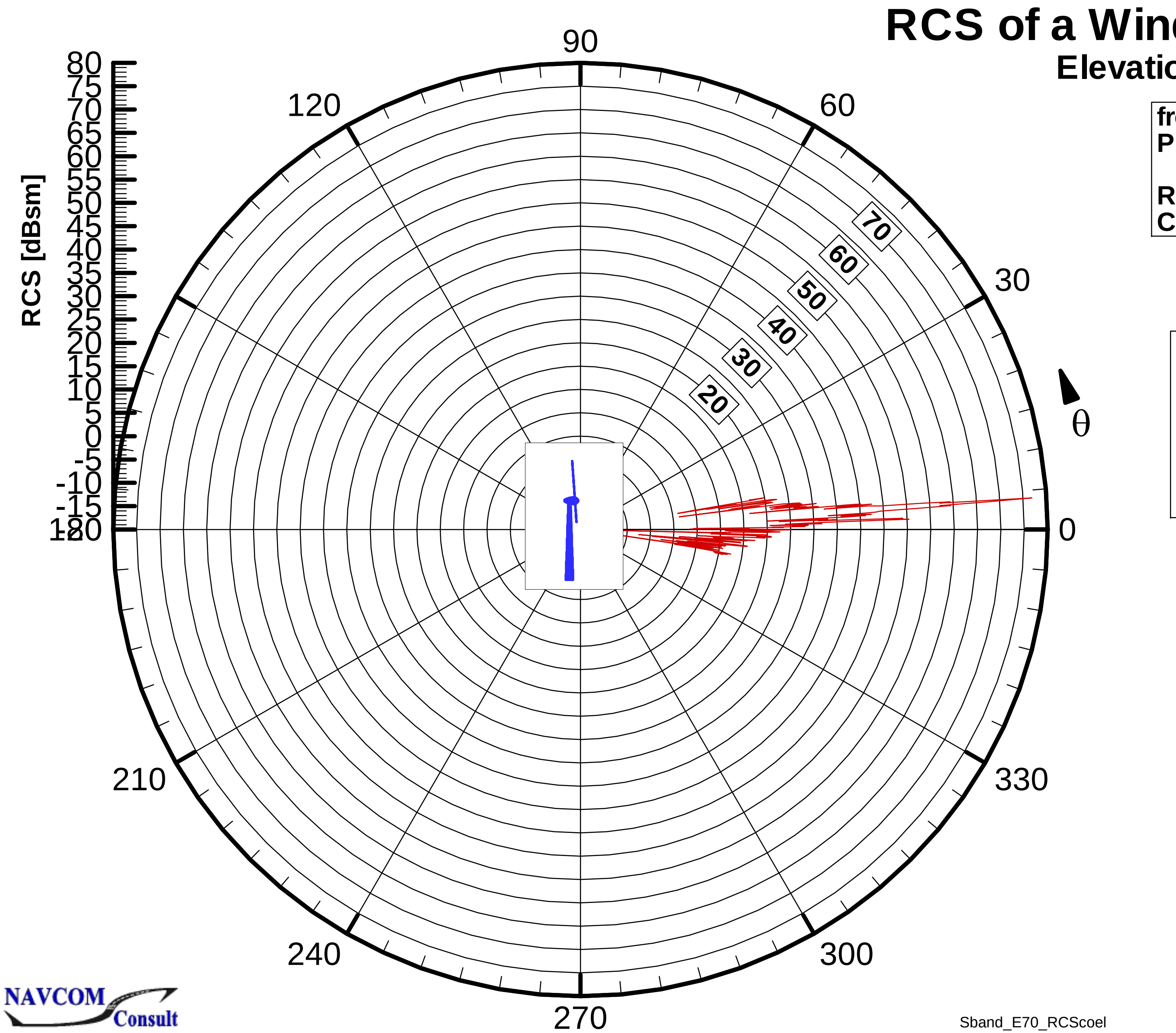
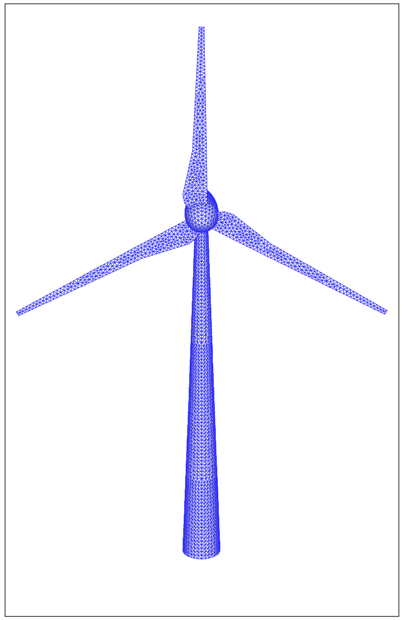
RCS is a 3D-function in free space → elevation





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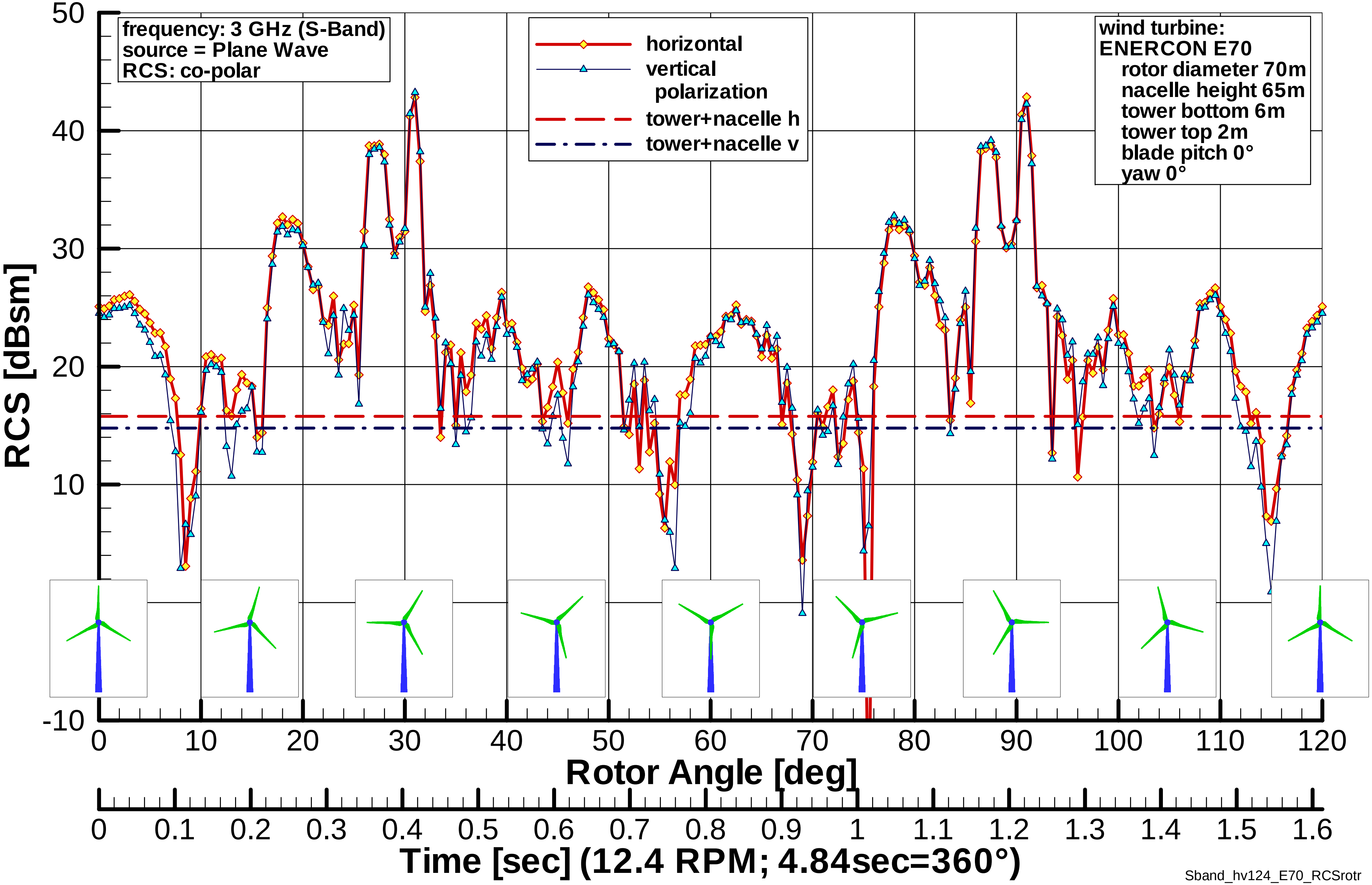
Radar Cross Section (RCS) of a Wind Turbine

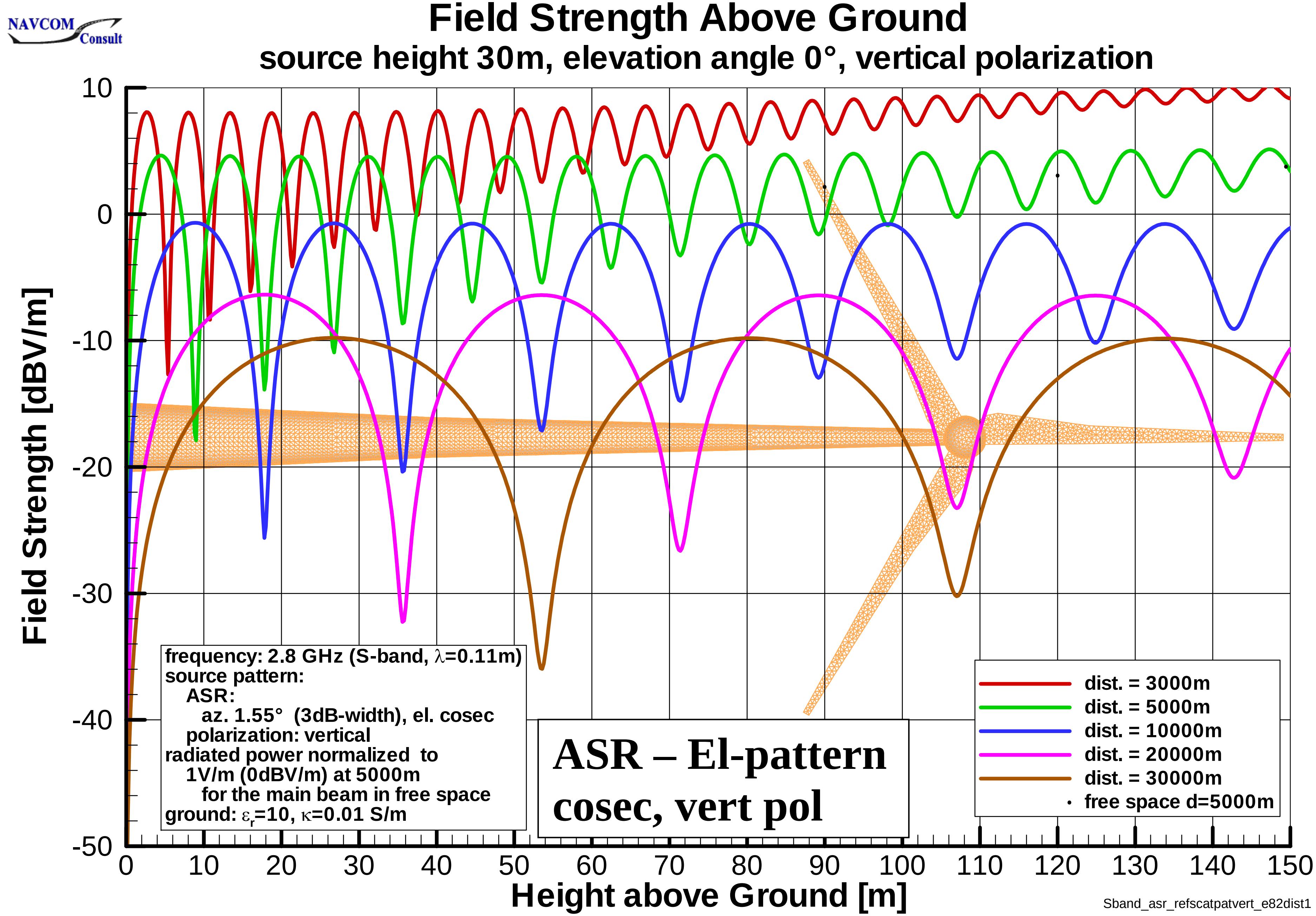
Varying Rotor Position



Sband_hv124_E70_RCSrotr

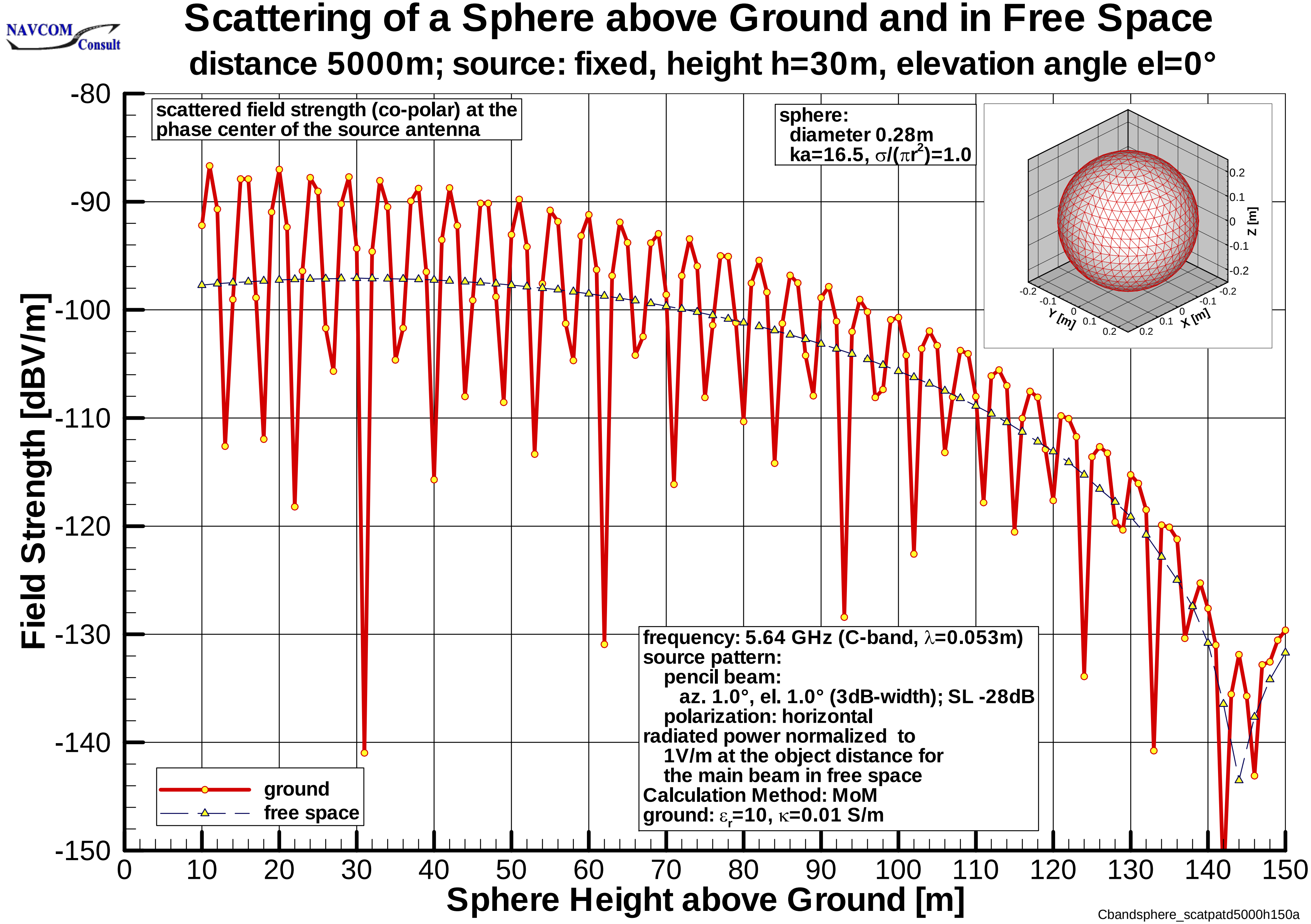
Field Strength Above Ground

source height 30m, elevation angle 0°, vertical polarization



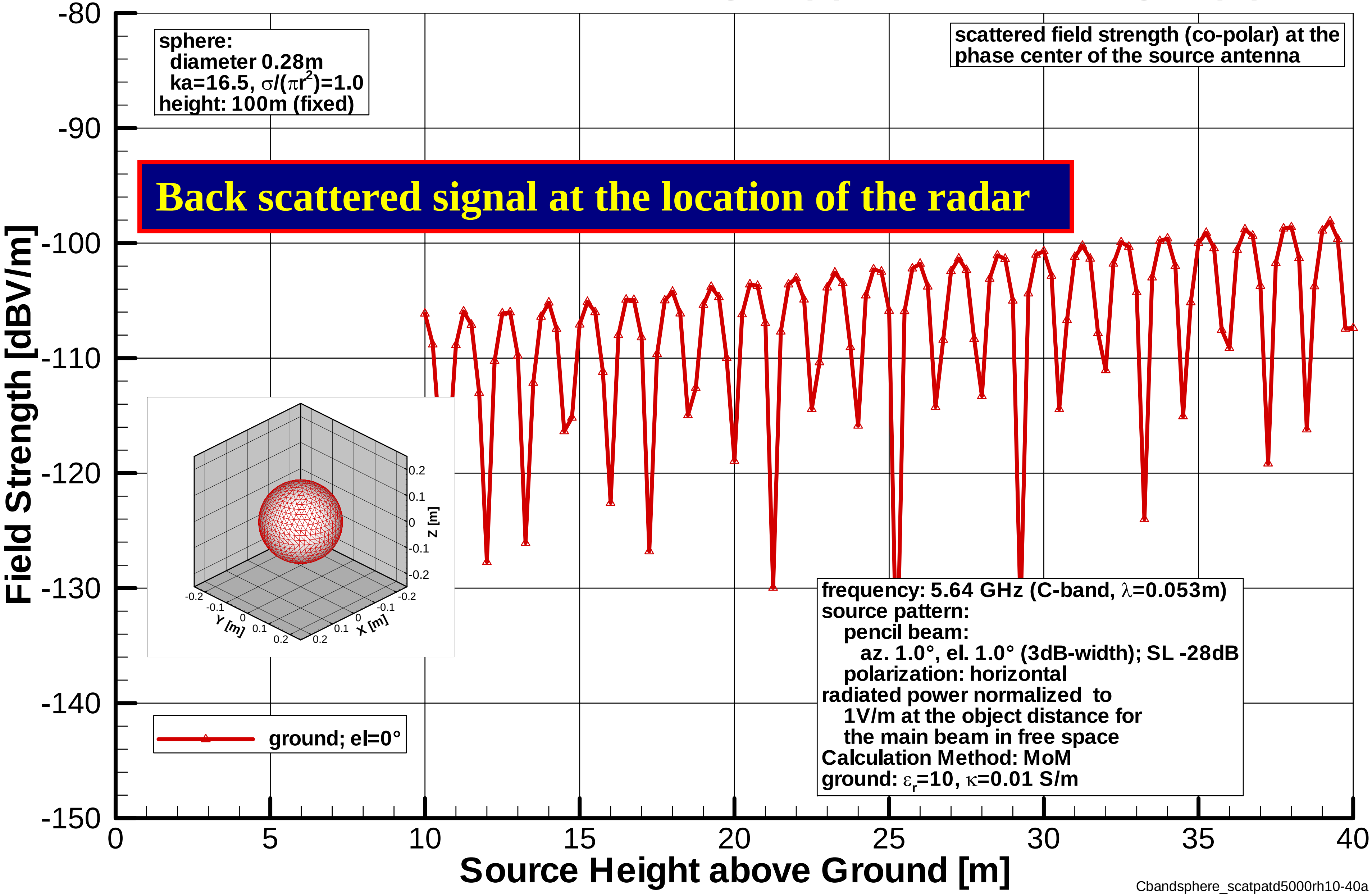
Scattering of a Sphere above Ground and in Free Space

distance 5000m; source: fixed, height h=30m, elevation angle el=0°



Scattering of a Sphere above Ground and in Free Space

distance 5000m; var. source heights (h), var. elevation angles (el)



Measures to reduce/improve effects

⇨ for all frequencies ? ←→ system

⇨ under all environmental conditions ? (rain, ice, …)

⇨ Absorbing material ? ←→ "forward scatter"

inside blades for lightning arrestor ←→ rain, carbon fibre

inside the nacelle shell ←→ rain, aluminum

increases shadowing

⇨ Stealth principles ? by form and construction

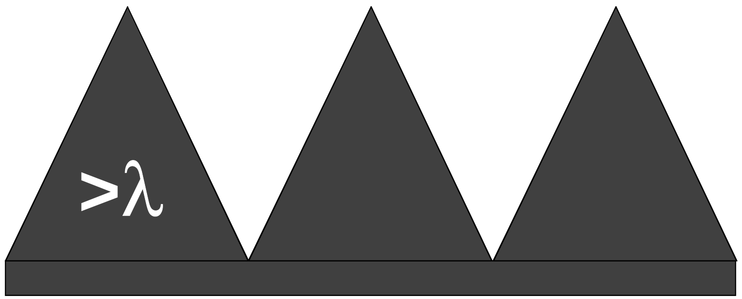
Effective almost only for back scatter

Not effective for forward scatter and bi-scatter (SSR,MSSR)

Not realistic solutions ←→ function and technology

Some types of existing real absorbers

broadband, light, thick

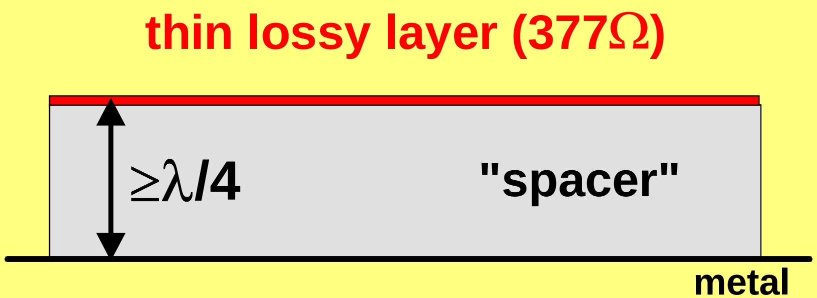


pyramidal foam absorber

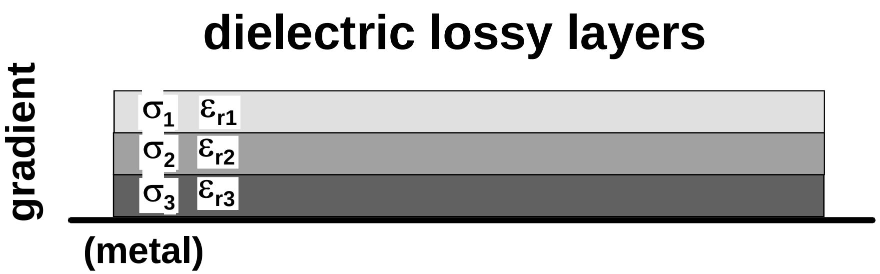
thin, heavy, narrow-band,expensive

ferrite magnetic absorber

transfer into heat



Salisbury Screen absorber



Jaumann absorber

Conclusions for Wind Turbines WT
Trivial qualitative results

- ⇨ The closer the WT the larger the distortions → far away
- ⇨ The more (close) WT the larger the distortions → single WT
- ⇨ The larger the WT the larger the distortions → smaller
- ⇨ The more metal the larger the distortions → non-metal

Do these qualitative results really help in case of a building application ?

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Conclusions for Wind Turbines WT

- ⇨ **The treatment of wind turbines is different for every system**
- ⇨ **Simulation scheme IHSS and numerical methods available**
- ⇨ **System Specifications, defined operational requirements to be met**
- ⇨ **Field interference fluctuations are not a criterion for system effects**
- ⇨ **Effects vs "comfort" - Can the mission be met?**
- ⇨ **scattering at WT is highly time- and space-variant**
- ⇨ **RCS scheme strictly speaking not applicable for WT**
- ⇨ **Modern HW/SW technology → by far better compatibility with WT**
- ⇨ **Examples of results for several systems presented**
- ⇨ **Advanced system simulations on case by case basis necessary**

Wind Turbines in the Radiation Field of Systems from a Prediction and Siting Point of View

THX - Q&A

http://www.navcom.de

w