On Numerical 3D-system simulations and Systems applied for Wind-Turbines

Über Numerische 3D-System-Simulationen und Systeme für Windkraftanlagen

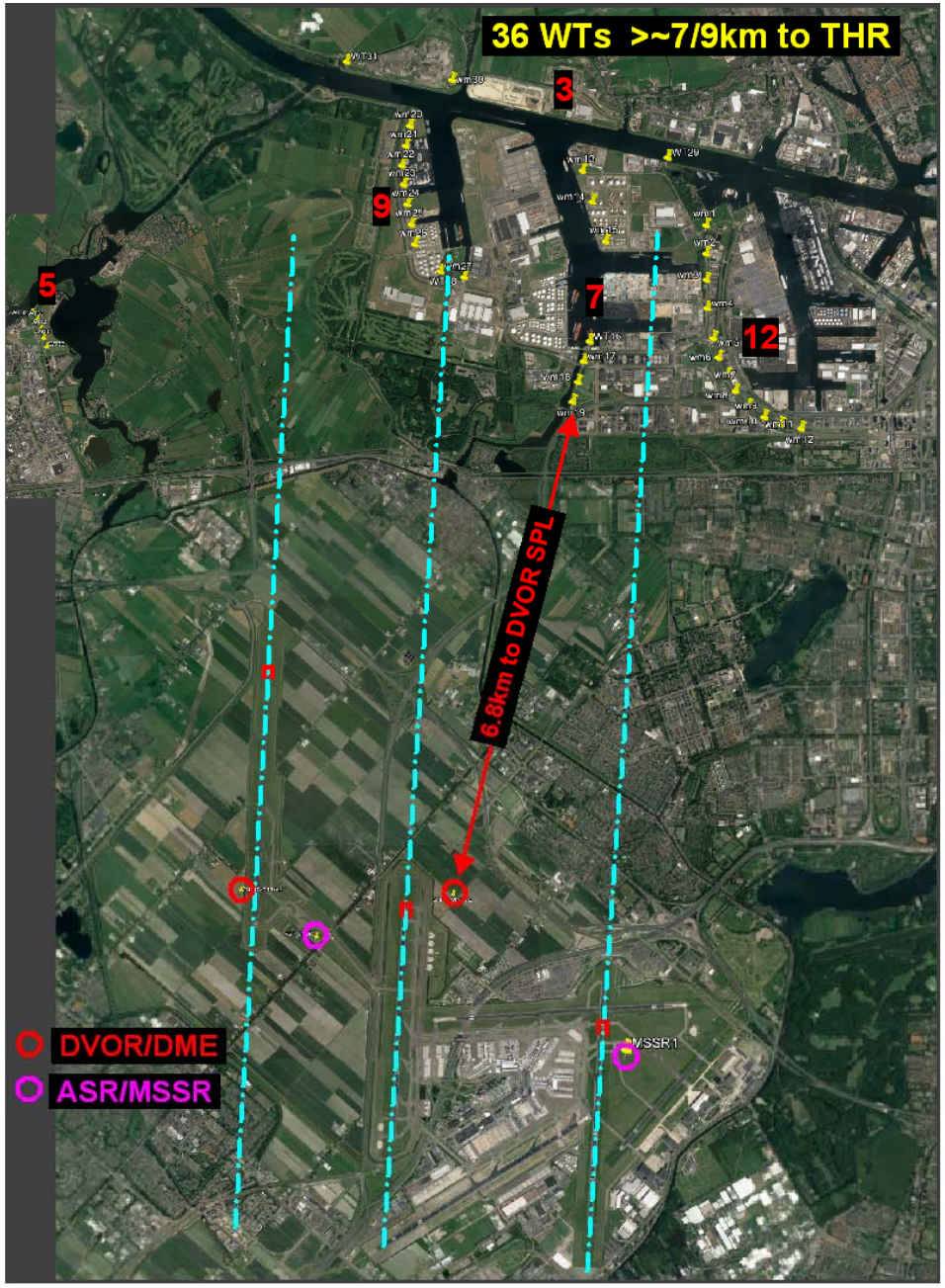
Gerhard Greving, Wolf-Dieter Biermann, Rolf Mundt

NAVCOM Consult
Ludwigsburgerstr. 43
D-71711 Steinheim / Germany

http://www.navcom.de

Content

- ⇨ Introduction - (inter-)national examples
- ⇨ Building applications for WTs (nav, rad, comm)
  Major problems: CVOR/DVOR, PSR, ADV Why?
- ⇨ Numerical system simulations Why? Background
- ⇨ 3D Modelling of the Systems and Wind Turbines
- ⇨ Remarks to the applied numerical IHSS-methodology
- ⇨ Examples; Validation and Verification of Simulations
- ⇨ Summary and Conclusions



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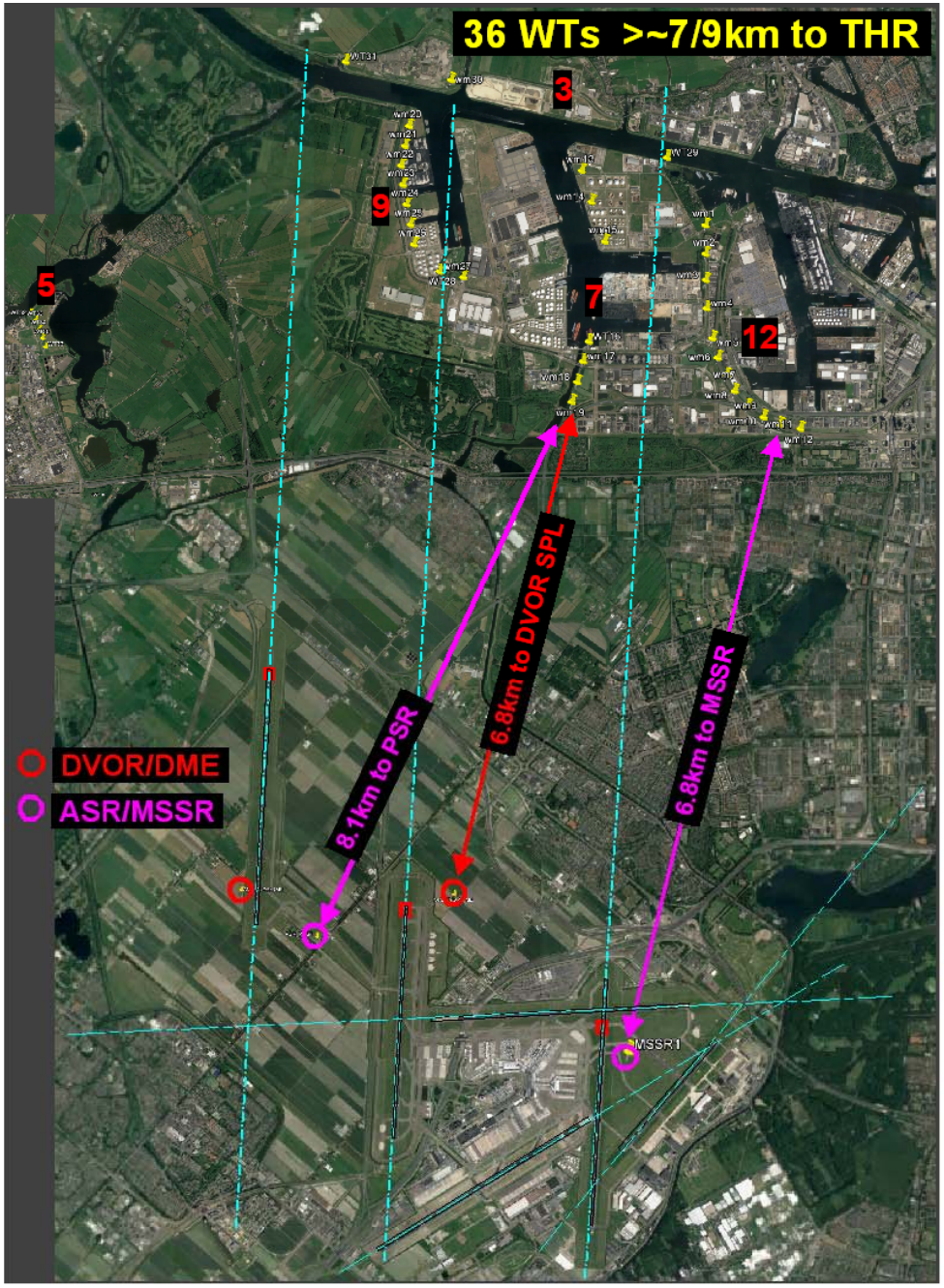
AMS_DVOR_ASR_Lay1.dsf 12/17

Amsterdam Schiphol : Close wind turbines in the radiation field of ILS, DVOR and ATC-radar



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Amsterdam Schiphol : Close wind turbines in the radiation field of ILS, DVOR and ATC-radar

Luxembourg Windenergy-Park DVOR/DME-Diekirch

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LuxDVORmap1.dsf 11/02

2002

H_{ground}=ca. 505m
H_{top}=ca. 600m+

NO1 NO2 NO3 NO4 NO5 NO6 NO7 NO8 NO9 NO10

Park of total 10 windmills

generator-head of the windmills at about +2° related to DVOR-counterpoise

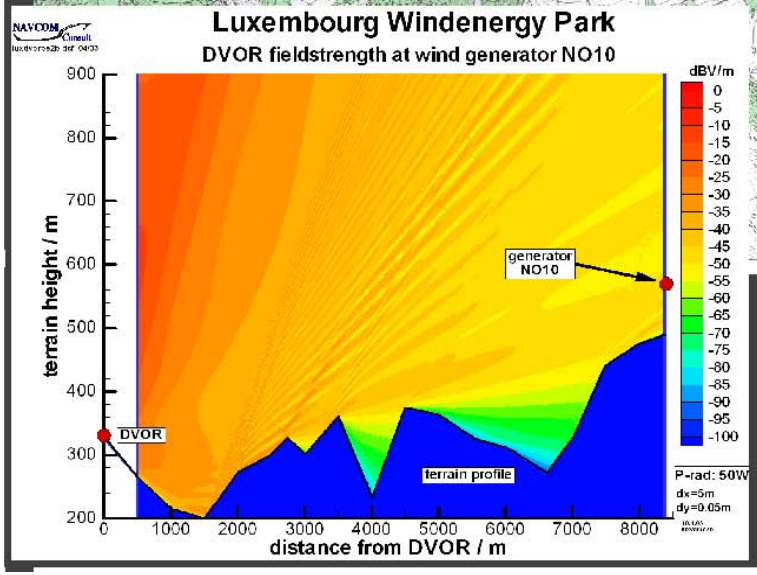
Hybrid 3D System Simulation: IPO+MoM+PE

ca. 2000m

ca. 8400m

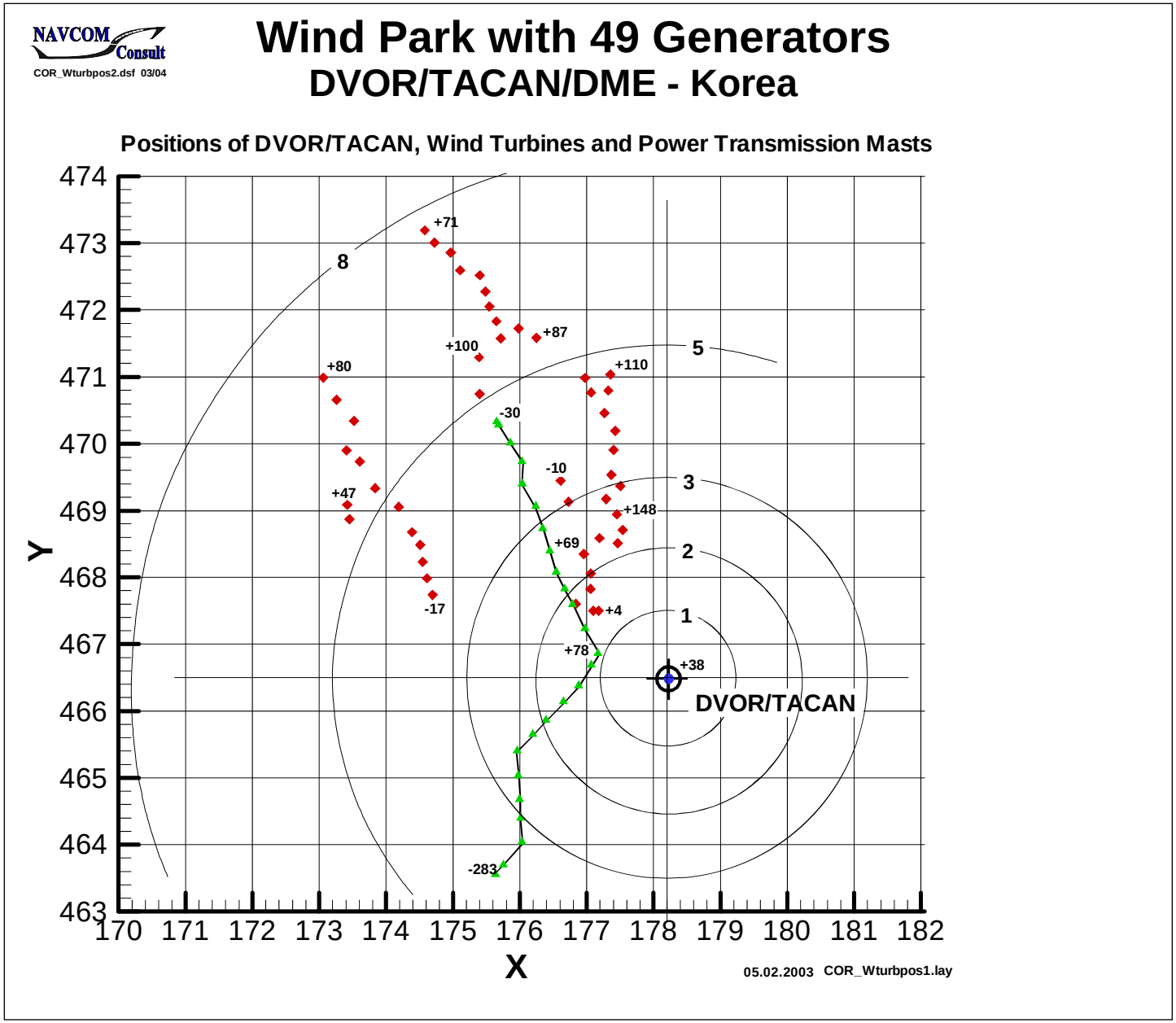
DVOR/DME-Diekirch

H=ca. 320m



Since 2004 operation and flightcheck !

1st large WP 2003/2004



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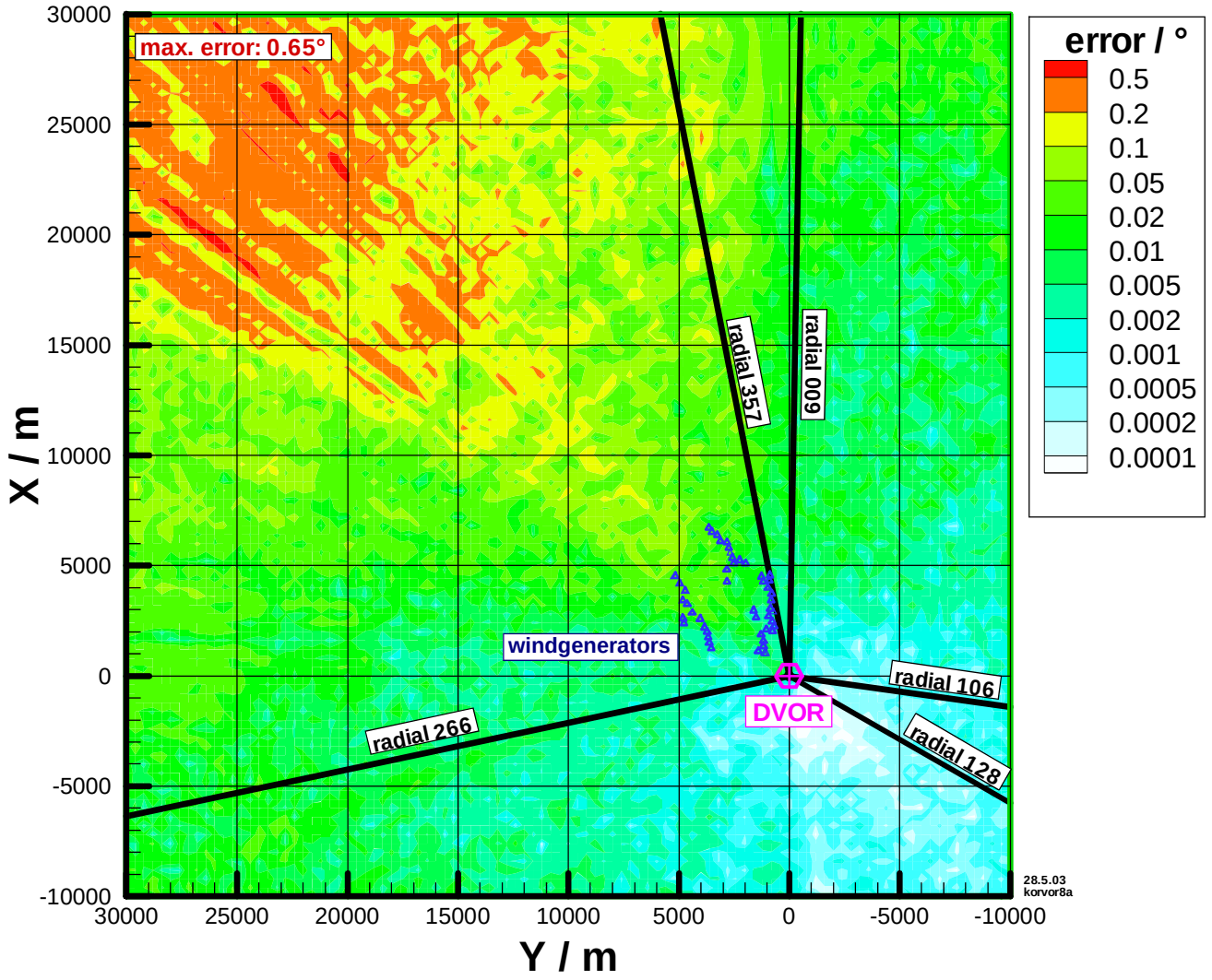
kordvorerr49wg1.dsf 06/03

Windpark and DVOR/TACAN - Korea

Bearing error in 7500ft MSL , 49 windgenerators



Windfarm Gangwon Korea

Project 2003

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Korea_DVORTAC_Lay1.dsf 11/17

7km

5km

3km

WT36 WT35 WT34 WT33 WT32 WT31 WT30 WT29 WT23 WT22 WT27 WT26 WT28 WT25 WT24 WT51 WT50 WT49 WT48 WT47 WT46 WT43 WT42 WT45 WT44 WT41 WT40 WT39 WT38 WT37 WT21 WT20 WT19 WT18 WT17 WT16 WT15 WT14 WT12 WT11 WT13 WT10 WT9 WT8 WT7 WT6 WT5 WT4 WT3 WT2 WT1 WT53 WT52

DVORTAC/DME KAE

1.2km

DVORTAC KAE

Total: 53 WTs V80
50 WTs wihtin 7km
12 WTs within 3km
closest distance 1.2km

Many years of operation and flightcheck since 2006

moutain top installation
dual counterpoise

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TR_VOR_wind_lay2.dsf 12/17

2012

Turkey: CVOR/DME and 24 WTs on a hill, d>8.9km

Hybrid 3D system simulation: IPO + MoM + PE

VOR/DME CRL

23

Airport Çorlu

05

Wind Farm Çanta Wepp

19 Wind turbines, Nordex N100

+ 5 WindTurbines Nordex N117

93°

8.9km

valley

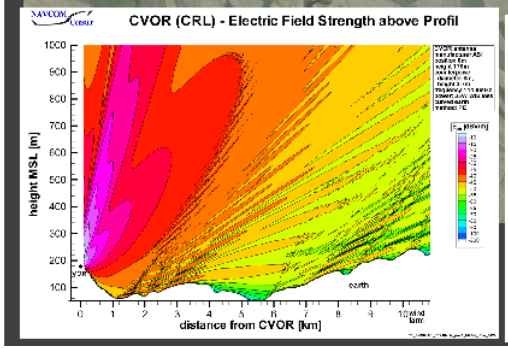
hill

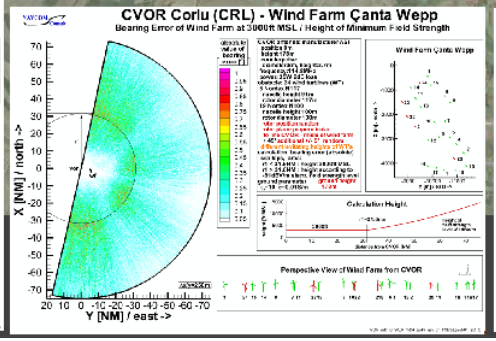
5km

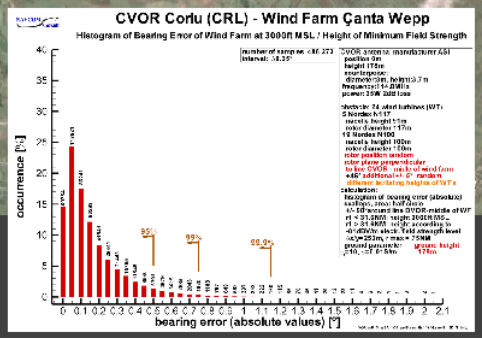
125°

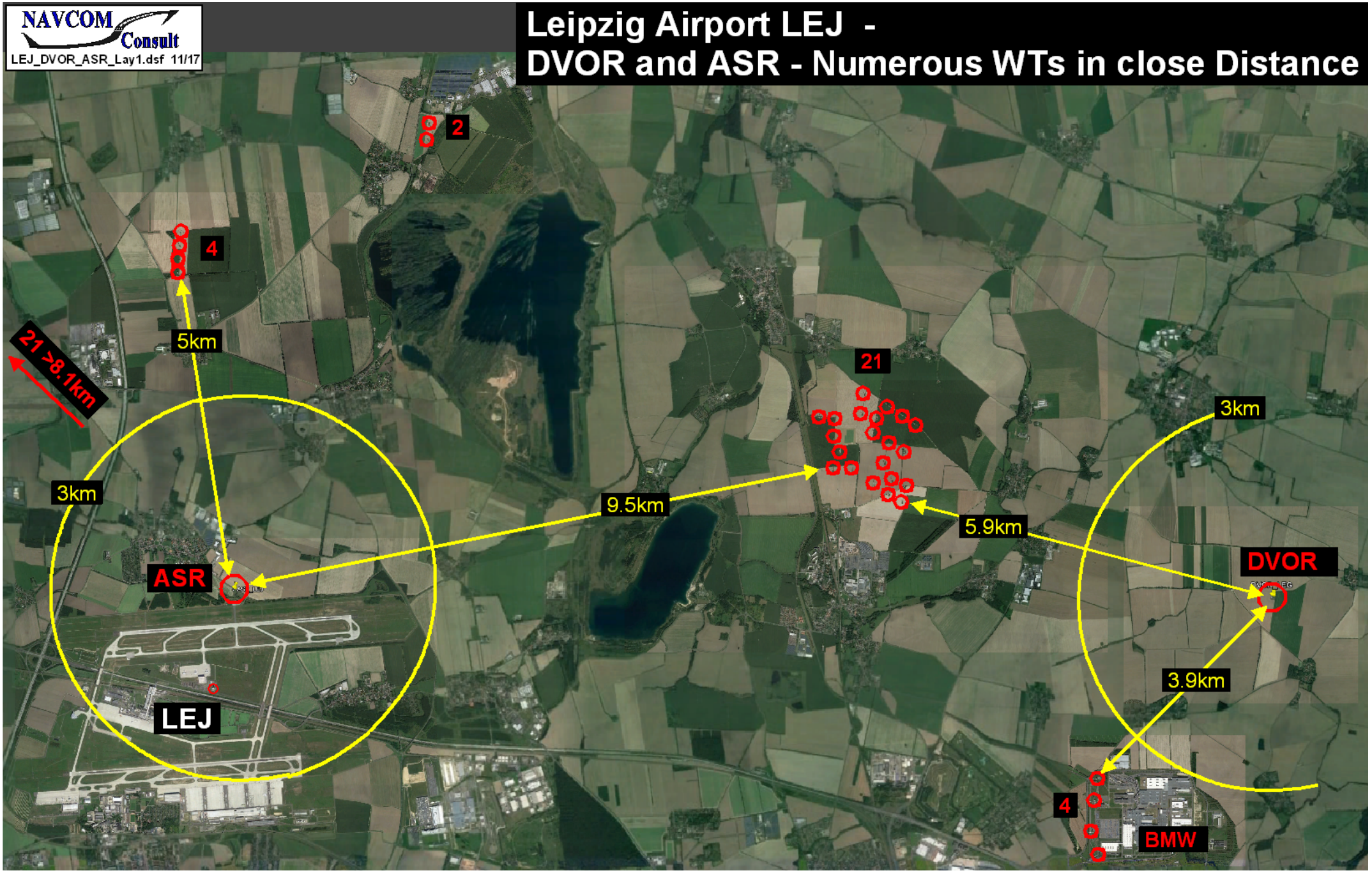
10km

Since ca. 2014 in successful operation + flightcheck
(ICAO DOC 8071)





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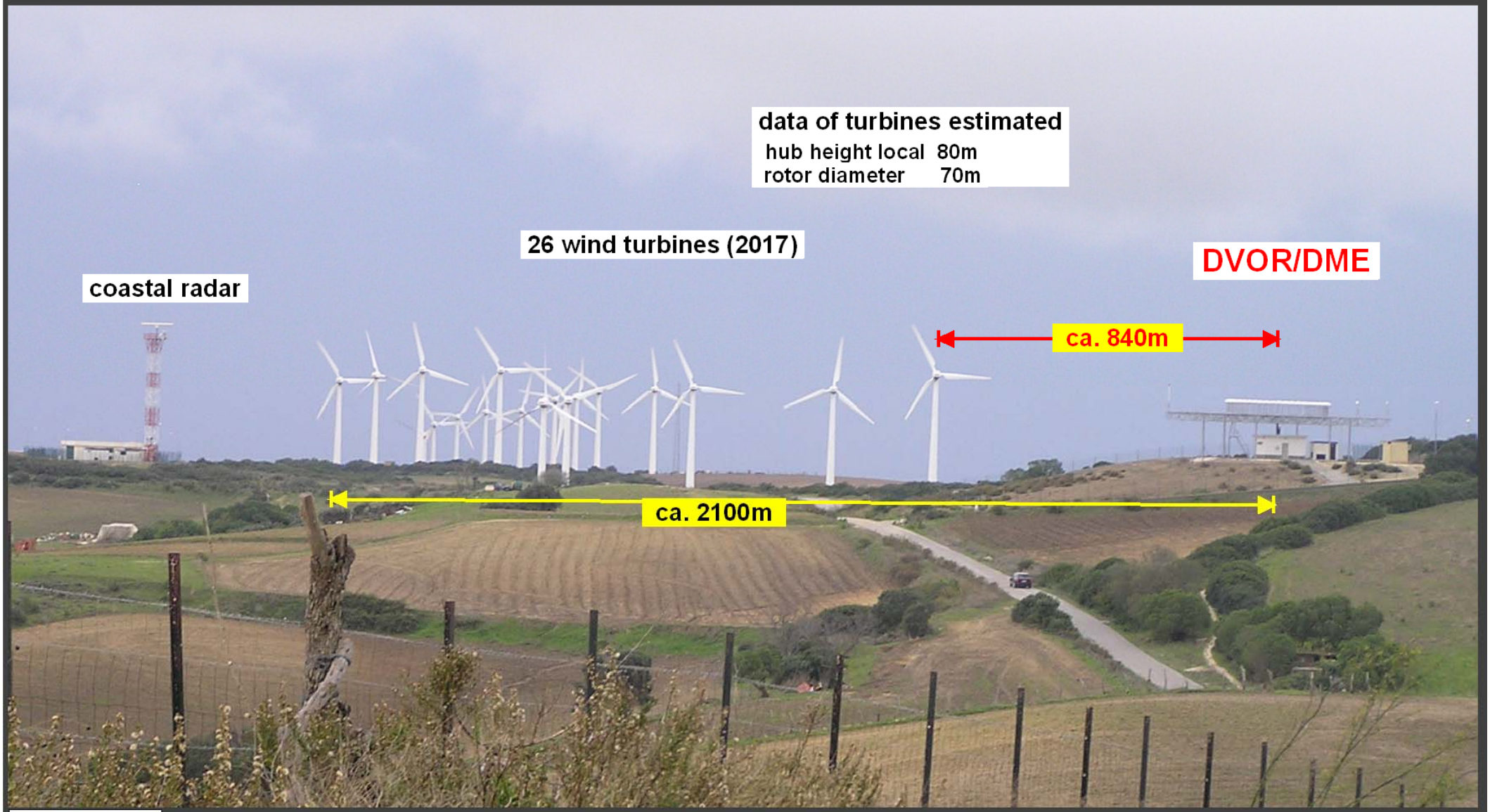
LEJ_DVOR_ASR_Lay1.dsf 11/17
Leipzig Airport LEJ -
DVOR and ASR - Numerous WTs in close Distance
2
4
5km
21 >8.1km
21
3km
9.5km
5.9km
3km
ASR
DVOR
LEJ
3.9km
4
BMW

DVOR/DME Vjer/Spain and very close windfarm of wind turbines



DVORTAC CRP and existing close wind turbines (11/2011)

B: DVOR: 15km → 10km → 7km

Belgocontrol

Jeudi 28 septembre 2017

Belgocontrol veut aider à développer les parcs éoliens en Belgique

⋮

par un bureau d'étude externe. Pour protéger les radiobalises, les zones interdites ont été réduites d'un rayon de 5 km à 3 km et les zones où une limitation en nombre est d'application ont été réduites de 10 km à 7 km.

⋮

- Les zones oranges nécessiteront toujours une analyse. En fonction des dangers potentiels, l'analyse sera effectuée par un bureau d'étude externe (entre autres dans la zone de 10-16 km autour d'un radar secondaire) ou par Belgocontrol même (par ex. dans la zone de 3-7 km autour d'une radiobalise).

⋮

EC Regulation No. 216/2008 ←→ SES (Regulation #1070/2009)

REGULATION (EC) No 216/2008 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

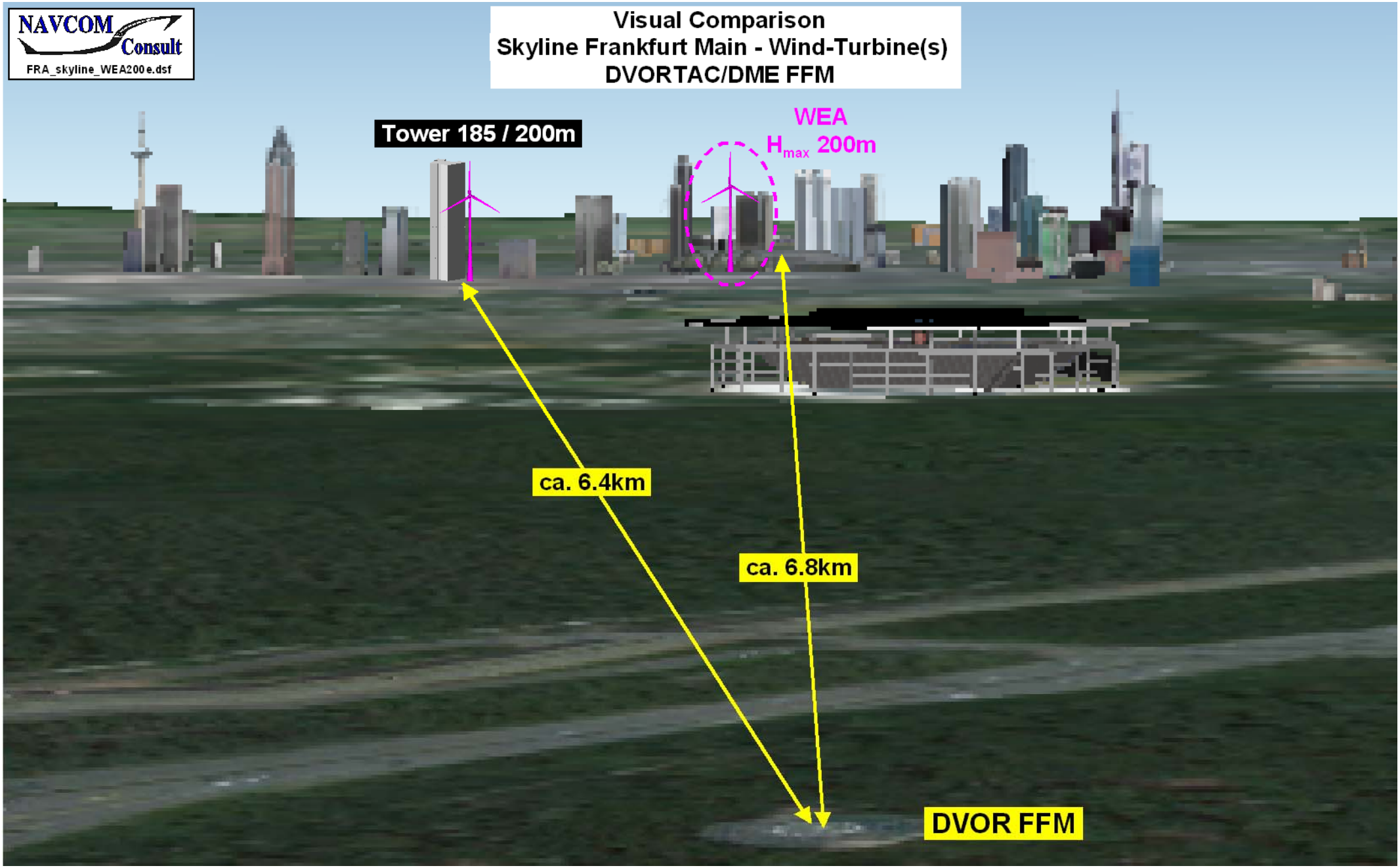
of 20 February 2008

on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC

(d) to assist Member States in fulfilling their obligations under the Chicago Convention, by providing a basis for a common interpretation and uniform implementation of its provisions, and by ensuring that its provisions are duly taken into account in this Regulation and in the rules drawn up for its implementation;

➔ **yearly audits of the member states by EASA**

➔ **periodic audits by USOAP ICAO**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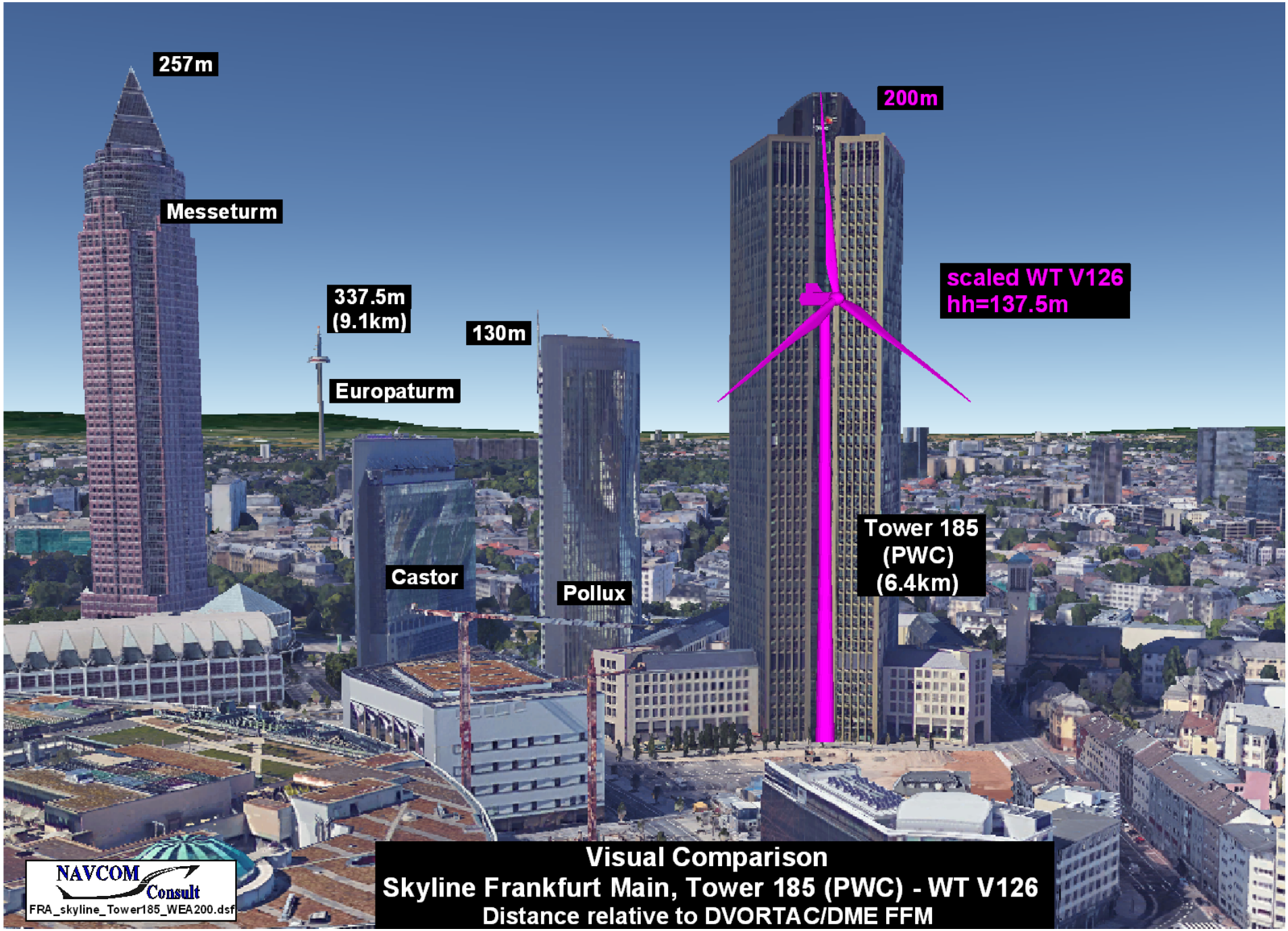
FRA_skyline_WEA200e.dsf
Visual Comparison
Skyline Frankfurt Main - Wind-Turbine(s)
DVORTAC/DME FFM
Tower 185 / 200m
WEA
Hmax 200m
ca. 6.4km
ca. 6.8km
DVOR FFM


257m
Messeturm
337.5m
(9.1km)
Europaturm
130m
Castor
Pollux
200m
scaled WT V126
hh=137.5m
Tower 185
(PWC)
(6.4km)
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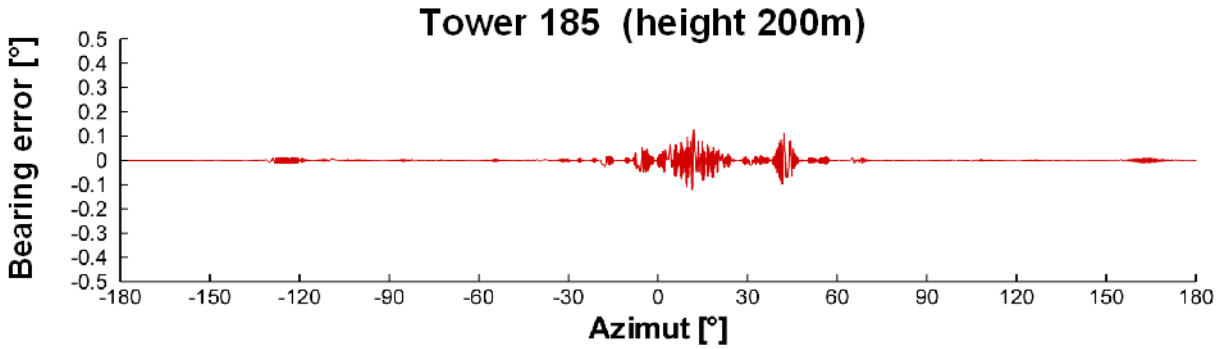
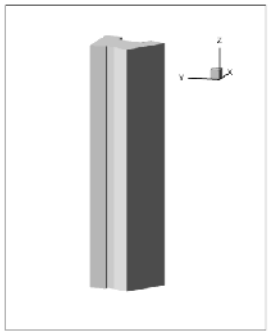
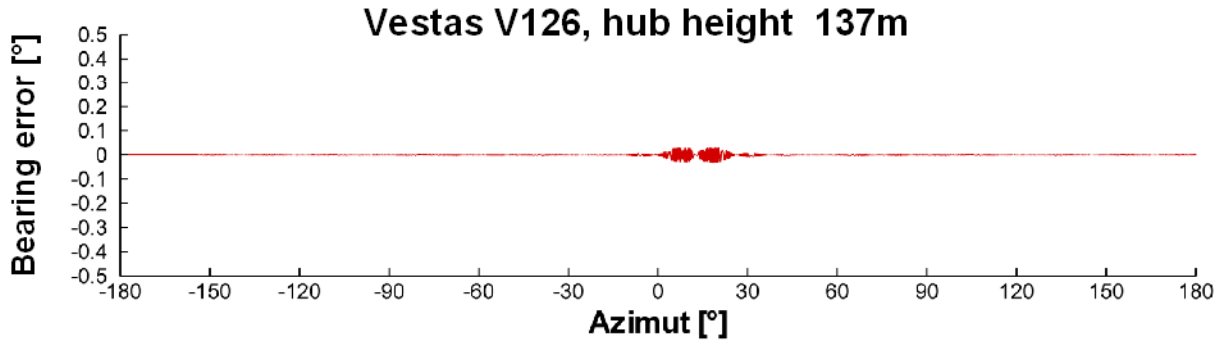
FRA_skyline_Tower185_WEA200.dsf
Visual Comparison
Skyline Frankfurt Main, Tower 185 (PWC) - WT V126
Distance relative to DVORTAC/DME FFM

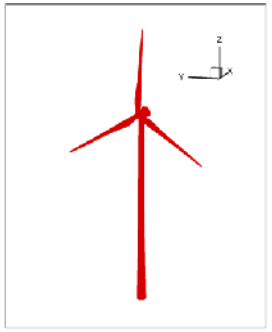
Frankfurt am Main - DVORTAC FFM

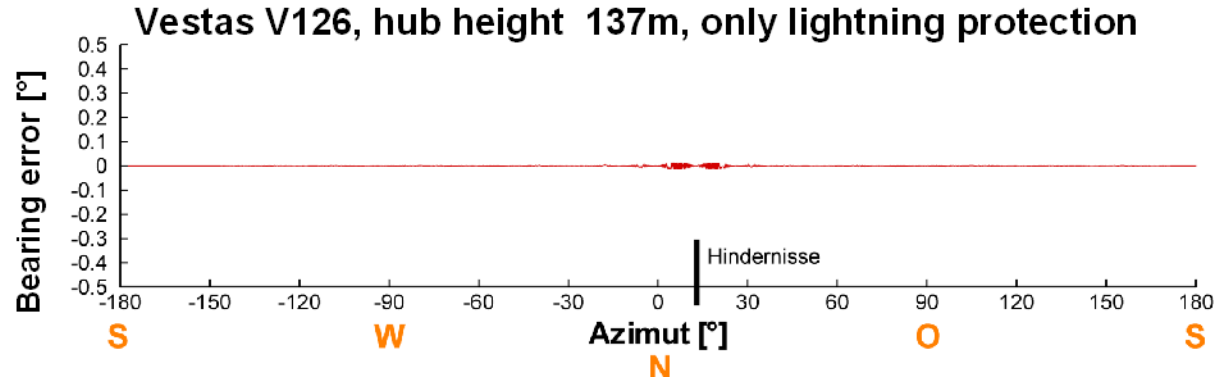
DVOR Bearing-Error; orbit height 2000ft, radius=10nm

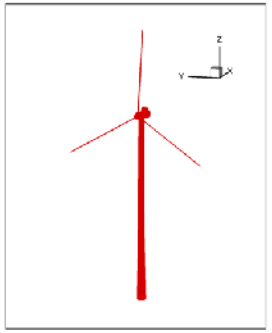


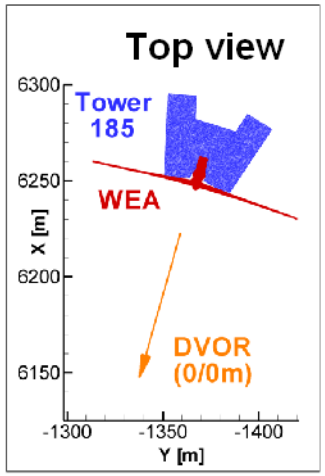












DVOR Antenne
Position x:0m y:0m
Gegengewicht
height: 4
Durchmesser: 30m
Frequenz: 114.2MHz

Hindernis
- Tower 185 (Höhe 200m)
- Vestas V126
  Nabenhöhe 137m
  Spitze 200m
- Vestas V126
  Nabenhöhe 137m
  Rotor NUR Biltzschutz
  Spitze 200m

Abstand zur DVOR 6430m

Berechnung
DVOR Winkelfehler
im Orbit 2000ft Höhe
Radius 10NM, Δ=0.5°
Scallops
Bodenparameter:
ε_r=10, σ=0.01S/m
method: IPO

DVOR_mD_FRA_vgl_Geb_V126_A

Decisive Components of Approval/Rejection WTs - Windfarms

- ⇨ **Which (international) Rules/Specifications are applicable ?**
  e.g. for navaids: ICAO Annex 10 acc. Chicago Convention
- ⇨ **Which distortions are present ?**
  Flight check and/or simulations
- ⇨ **Numerical 3D Simulations acc. “state-of-the-art” methods**
- ⇨ **Physical Correct superposition or de-composition of errors**
  ←→ complex vector fields, random components; rss
- ⇨ **Applications of common specs/rules ←→ EASA No. 216/2008**

System Simulations for ATC-Systems
Why ? Benefit ?

⇨ **To know the system performance in advance**

before the objects are build ←→ new Terminal, new Tower etc.

before the objects appear ←→ A380

⇨ **Siting and Installation Design Studies**

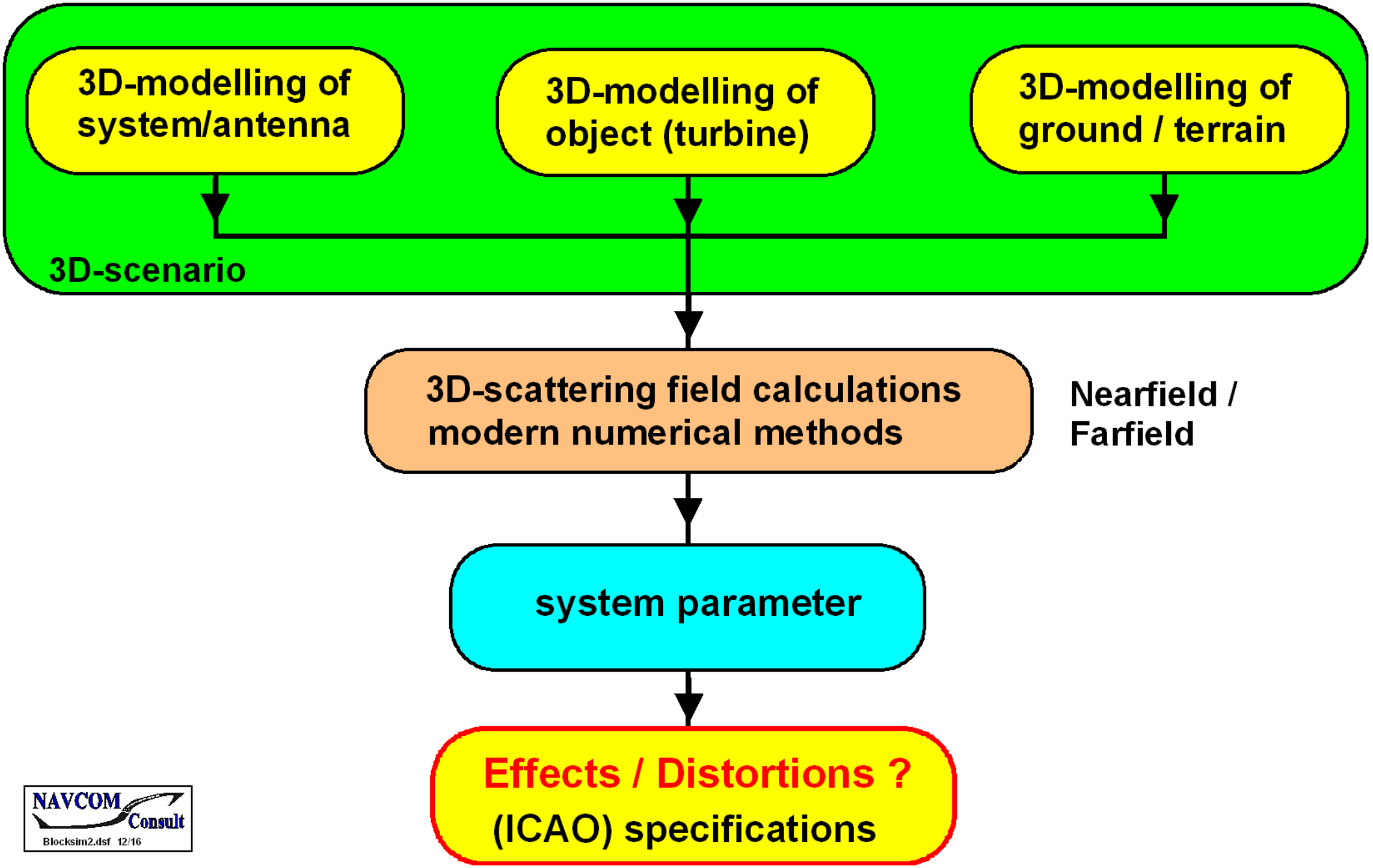
Which antennas or systems have to be installed for a given scenario

Where and how to install the Systems (e.g. ILS GP on 3D ground)

⇨ **Study / Design on Computers by Software + System Knowhow**

⇨ **Tests and Measurements not possible/feasible or too expensive**

→→ **Fast, reliable and accurate computer simulations**


3D-modelling of system/antenna
3D-modelling of object (turbine)
3D-modelling of ground / terrain
3D-scenario
3D-scattering field calculations modern numerical methods
Nearfield / Farfield
system parameter
Effects / Distortions ?
(ICAO) specifications
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Blocksim2.dsf 12/16

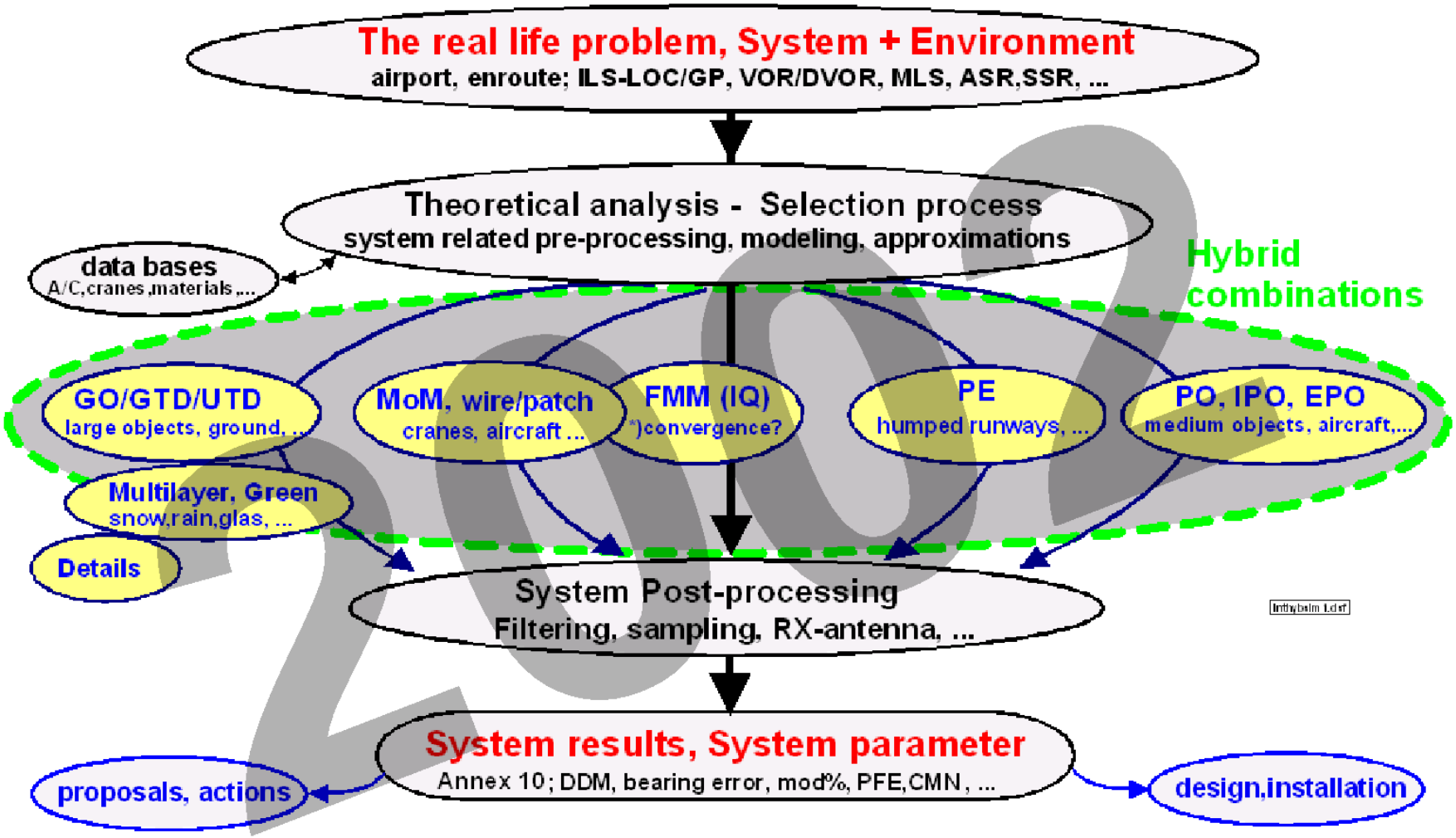
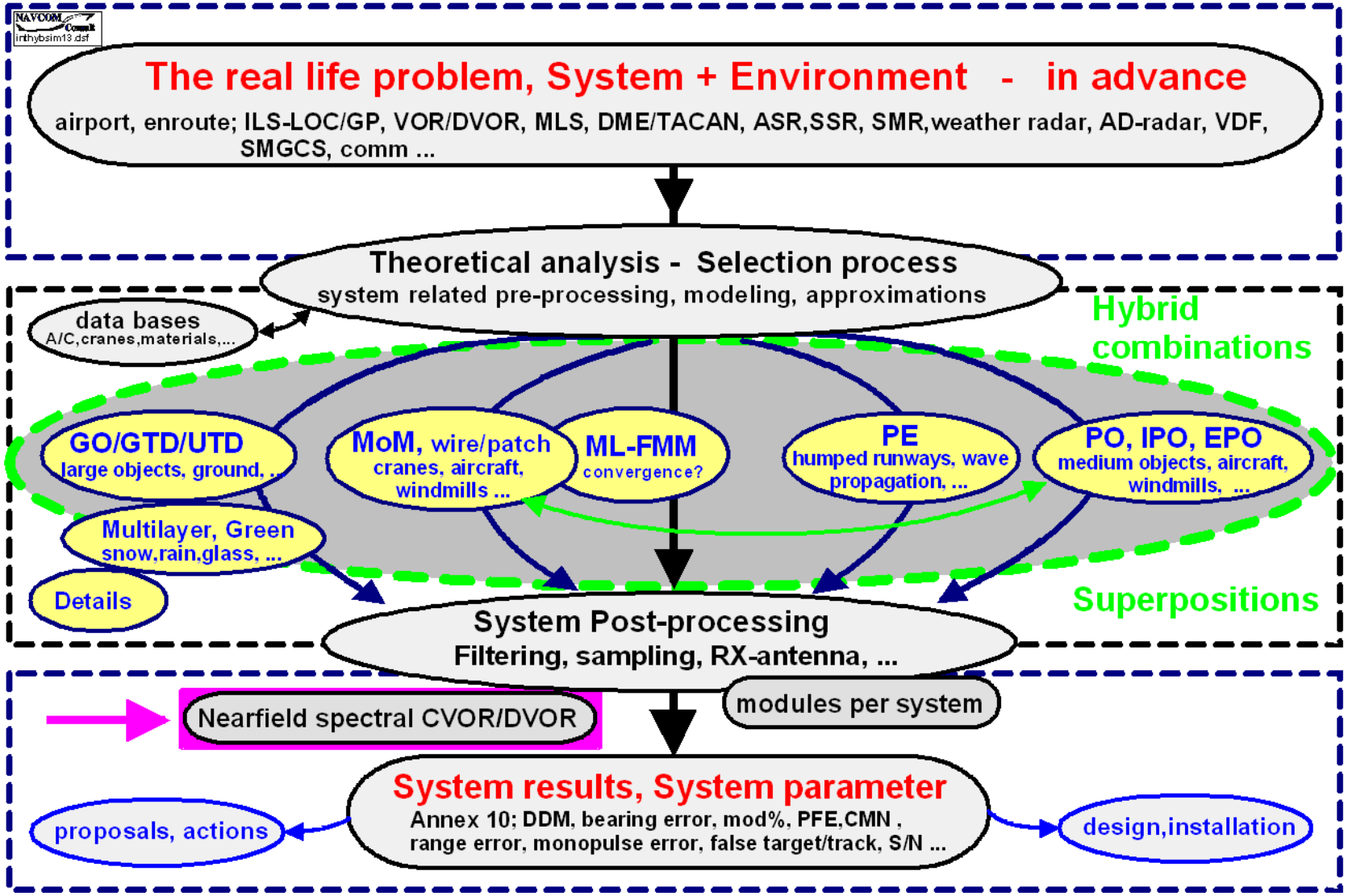


Fig. 2: The process flow of system simulations by the integrated hybrid approach

Gerhard Greving Latest Advances and Results of Complex Numerical Simulations for Navaids and Landings Systems; IFIS 2002 (International Flight Inspection Symposium), Rome Italy

Numerical System Simulations IHSS

An Integrated Hybrid System Simulation approach

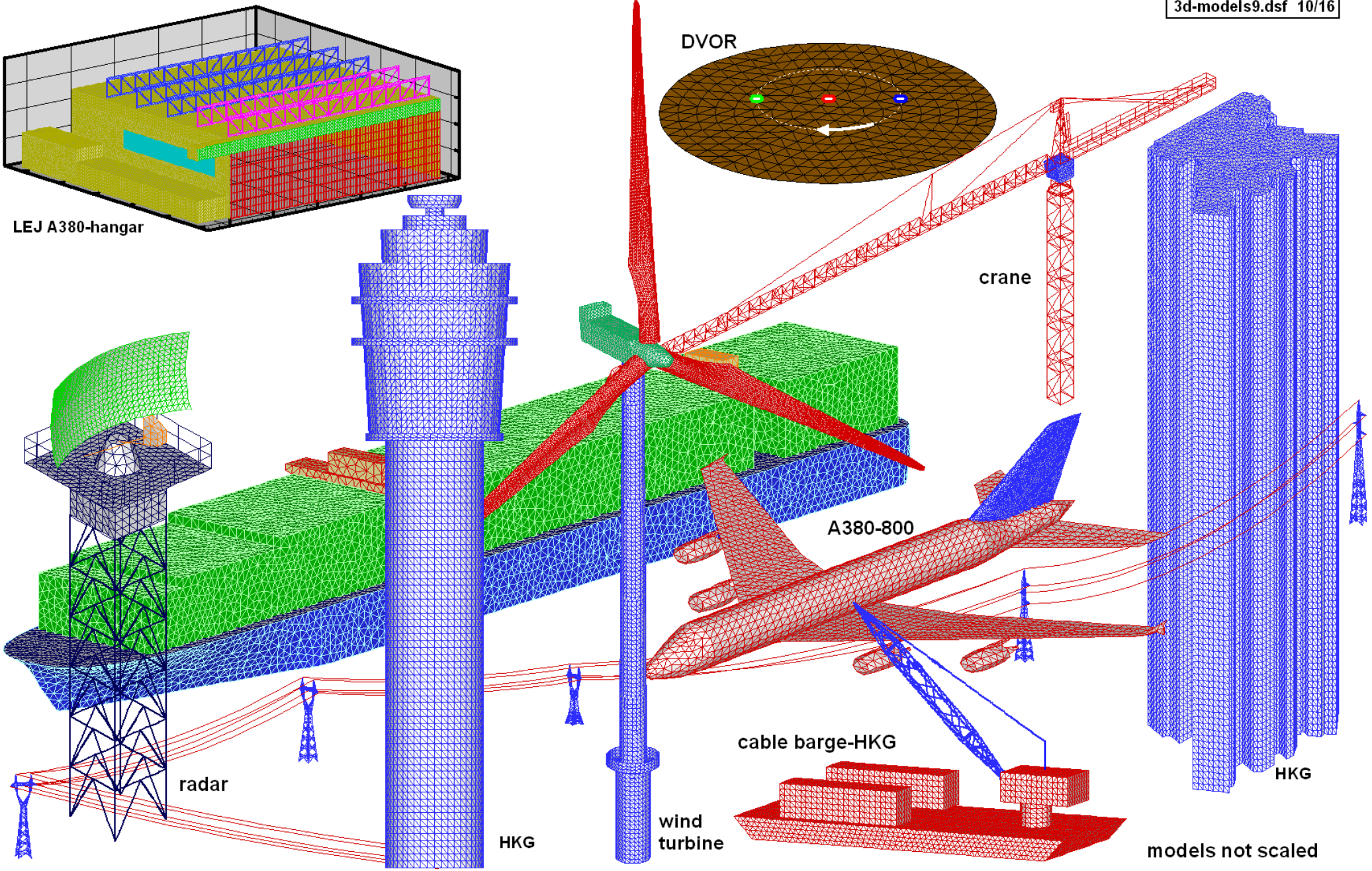


System pre-processing *Landing Systems, Navaids, Radar, VHF/UHF comm* **Modeling**

Numerical Methods Antennas, scattering objects ground effects, wave propagation

System post-processing *System parameter*

3D-Models and DVOR-antenna



Systems and 3D-objects

VOR/DVOR
110MHz

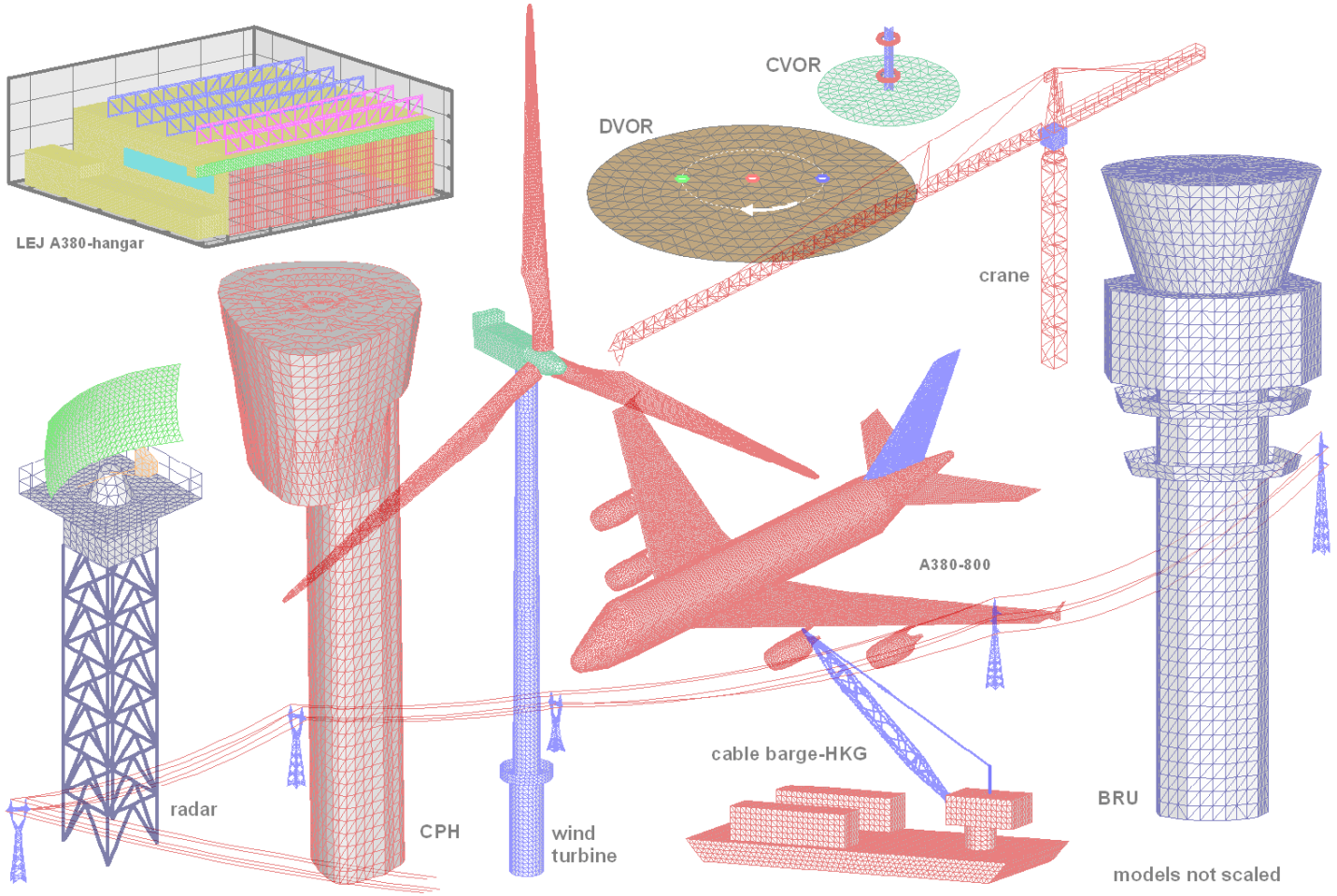
NDB
400kHz

ILS
110/330MHz

TACAN/DME
1GHz

GPS
1GHz

MLS
6GHz



MSSR
1GHz

PSR
3GHz

AD
1/3GHz

WR
3/6GHz

VDF
136MHz

Com
136/400MHz

Radio-Relay

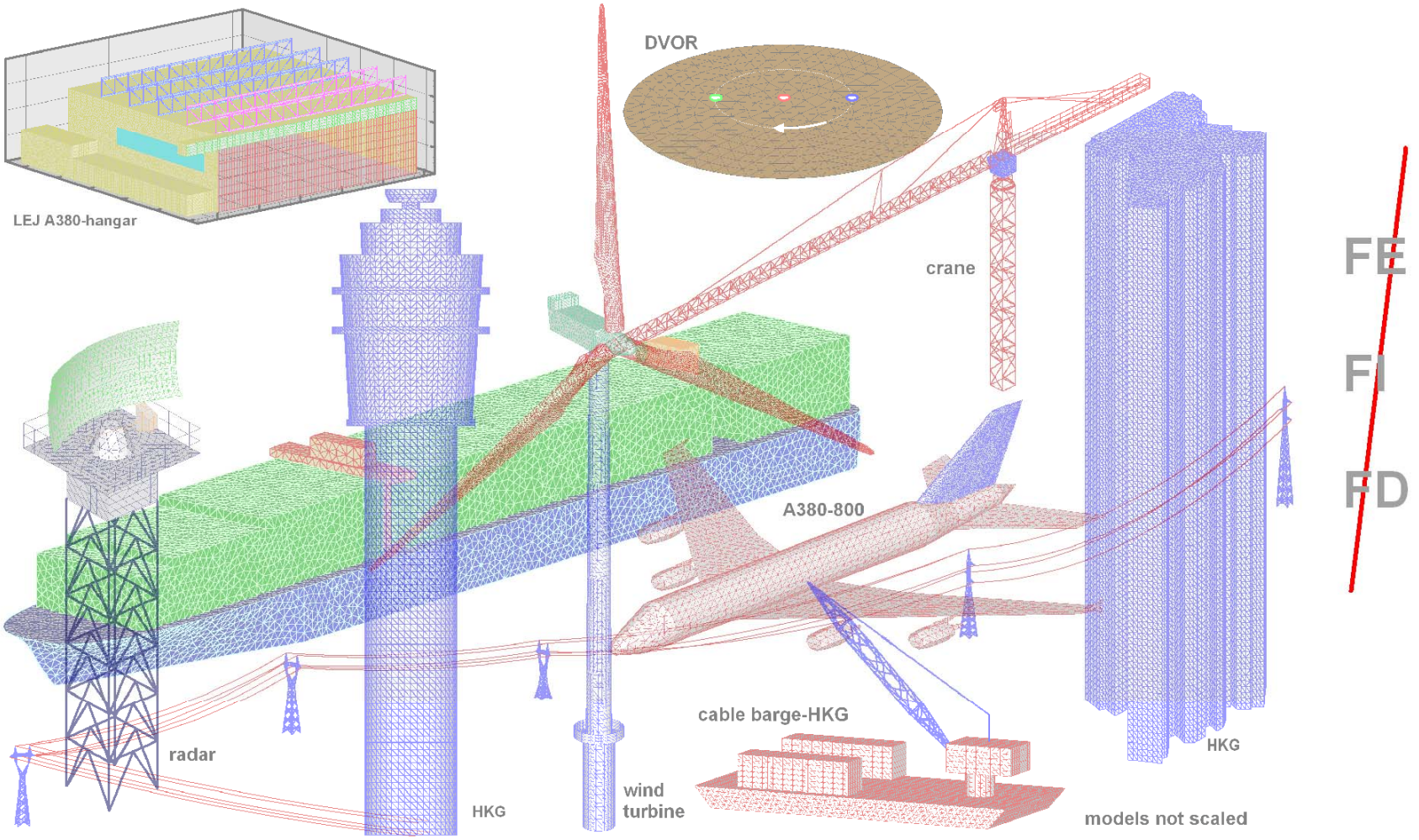
SMR/Marine
9GHz

Systems, 3D-objects and Numerical Methods

~~PO / IPO~~

GO
GTD
UTD

MoM
MLFMM



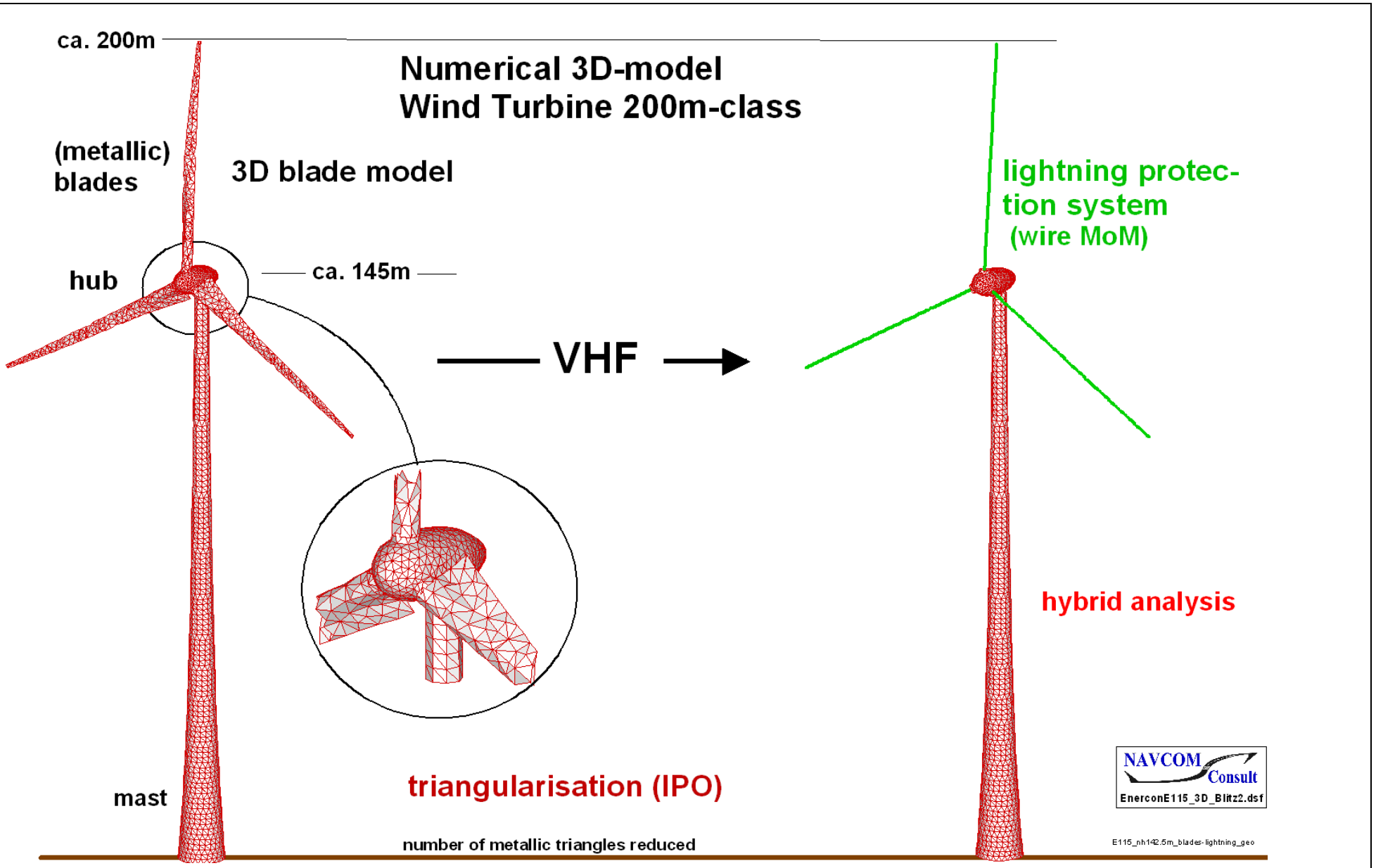
PE

multilayer/Greens

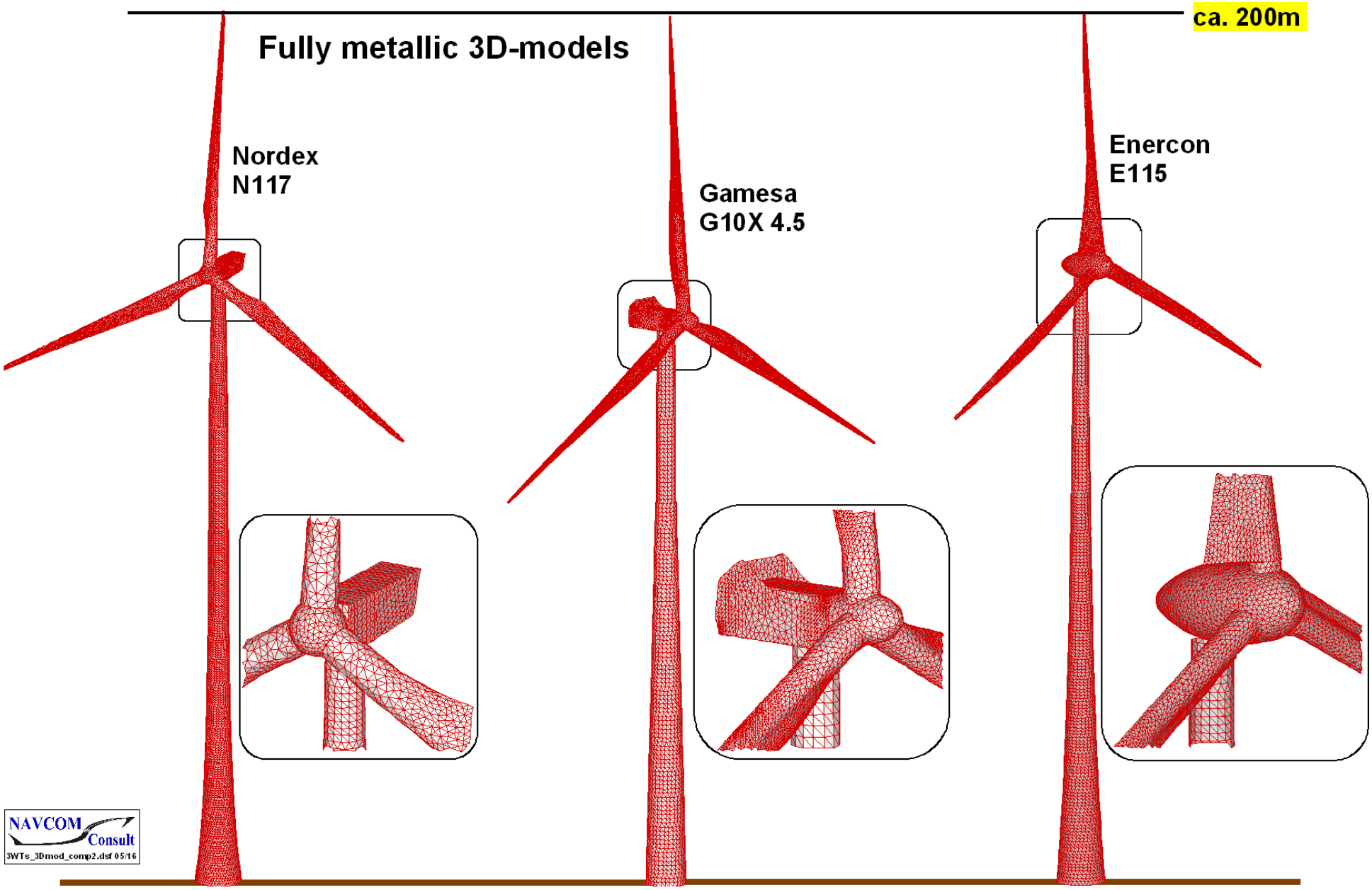
Hybrid combinations

3D-modelling of WTs

- ⇨ **mast**
- ⇨ **hub**
- ⇨ **blades**
- ⇨ **often metallic worst case**



Numerical 3D-Model of a large Enercon E101; 2 Versions



Three different 3D-models of very large fully metallic wind-turbines (200m class)

Examples of Simulations - Results

⇨ **Navigation**

⇨ **Radar**

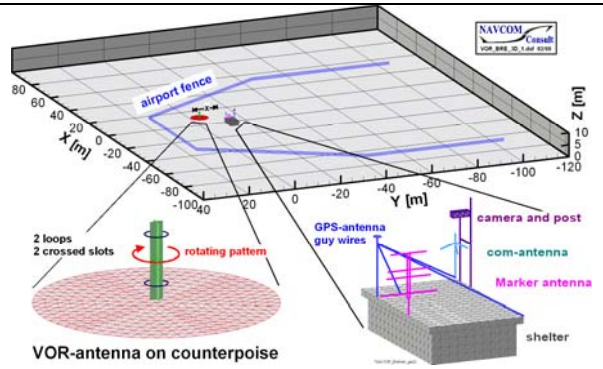
⇨

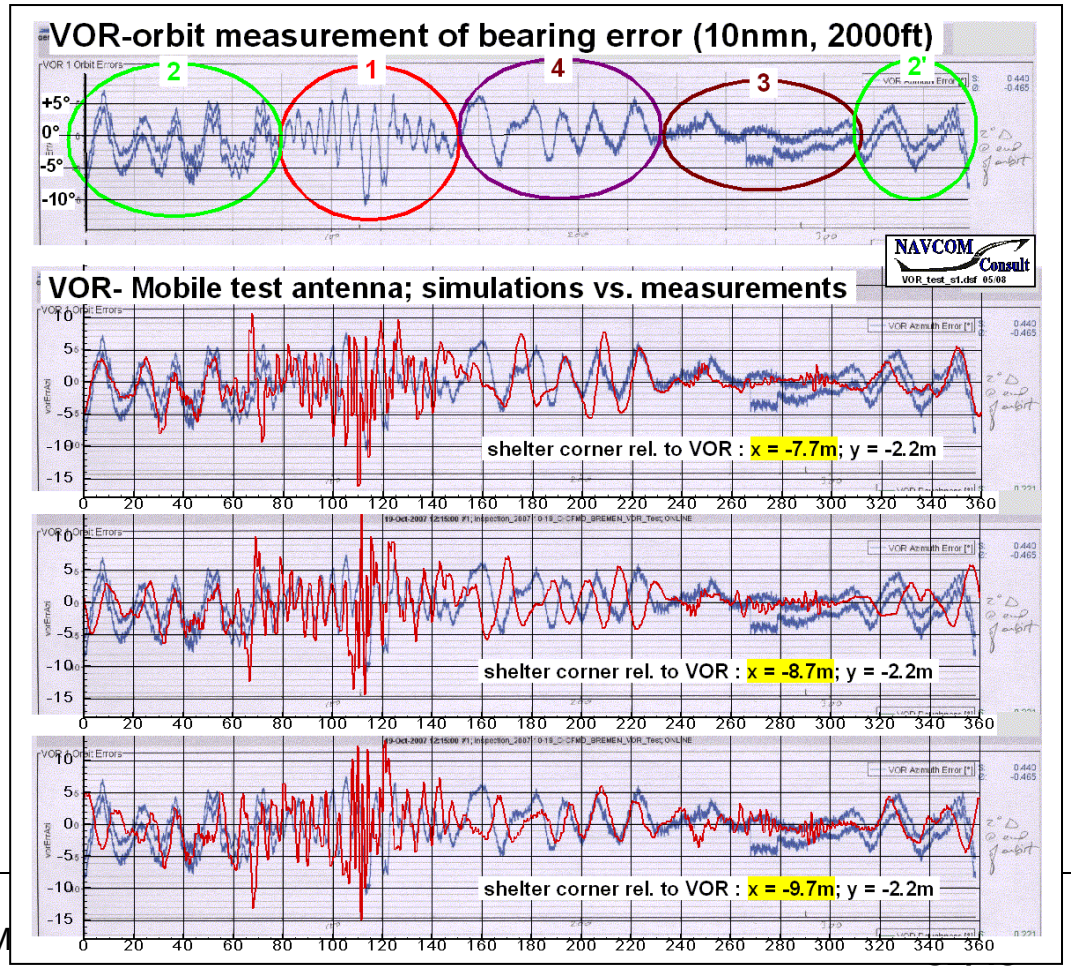
⇨ **Validation by measurements**
Validation by many years of successful operation

Validation and Verification of Methods/Results Guidelines

- **Continuous comparison with available (reliable) measure-ments.**
- **Application of knowhow, plausibility and experience, minimizing the probability of wrong/erroneous results.**
- **Use only of proven and generally applicable numerical methods**
- **Cross-check with other methods and other tools if available and possible.**
- **Carefully and consequently following the rules and limitations of the applied method ←→ requires deep knowhow**

Example : Very close shelter and objects; CVOR (-Navigation-system)





2006
VOR BRE

Verification of methodology

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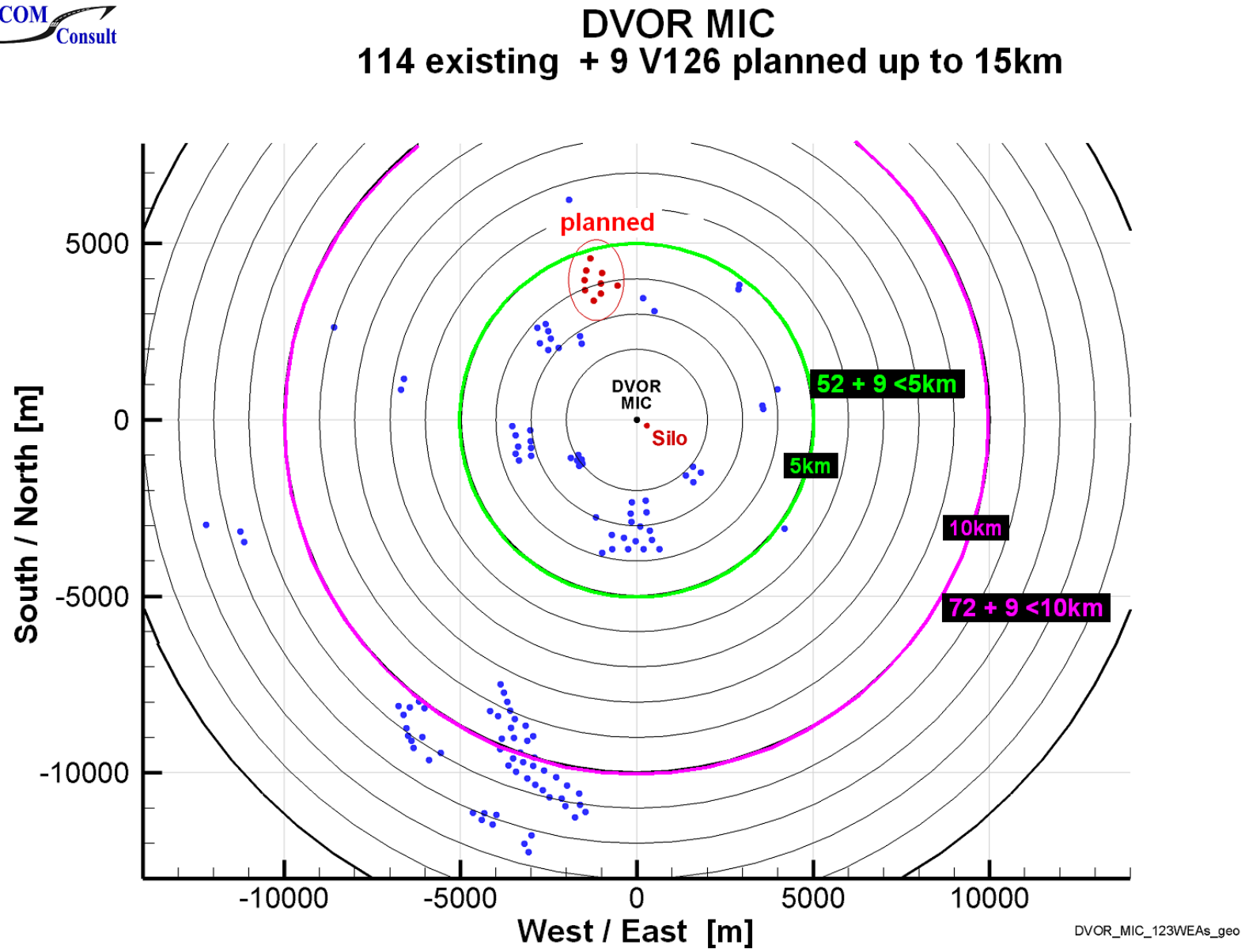
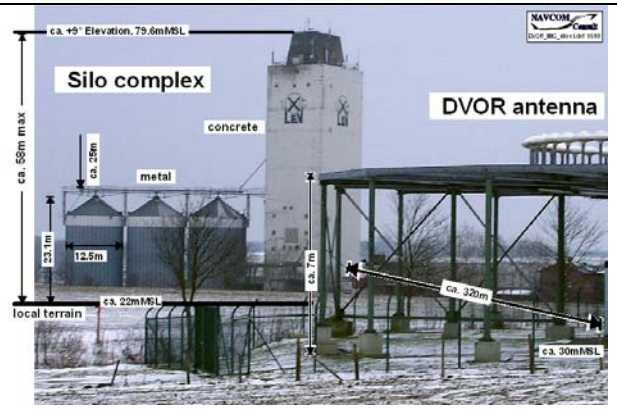
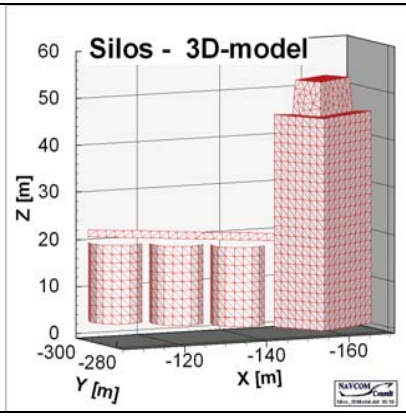
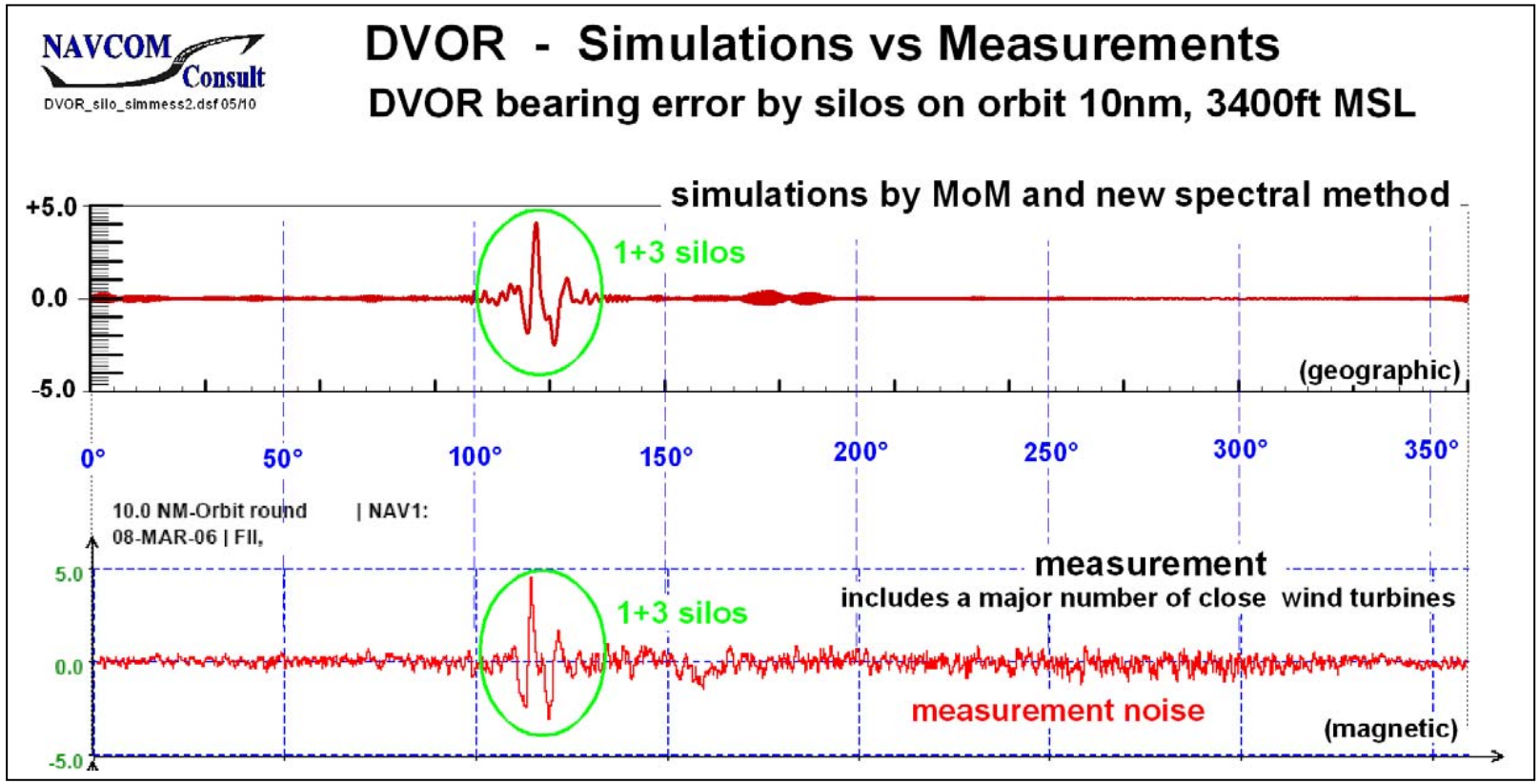


DVOR MIC; Layout of 123 WTs min up to 15km

Example : Very close silo-complex (320m) to a DVOR (-Navigation-system)







2009
DVOR MIC

Example 3: Very close control-tower (360m) and DVOR (Navigation-system)

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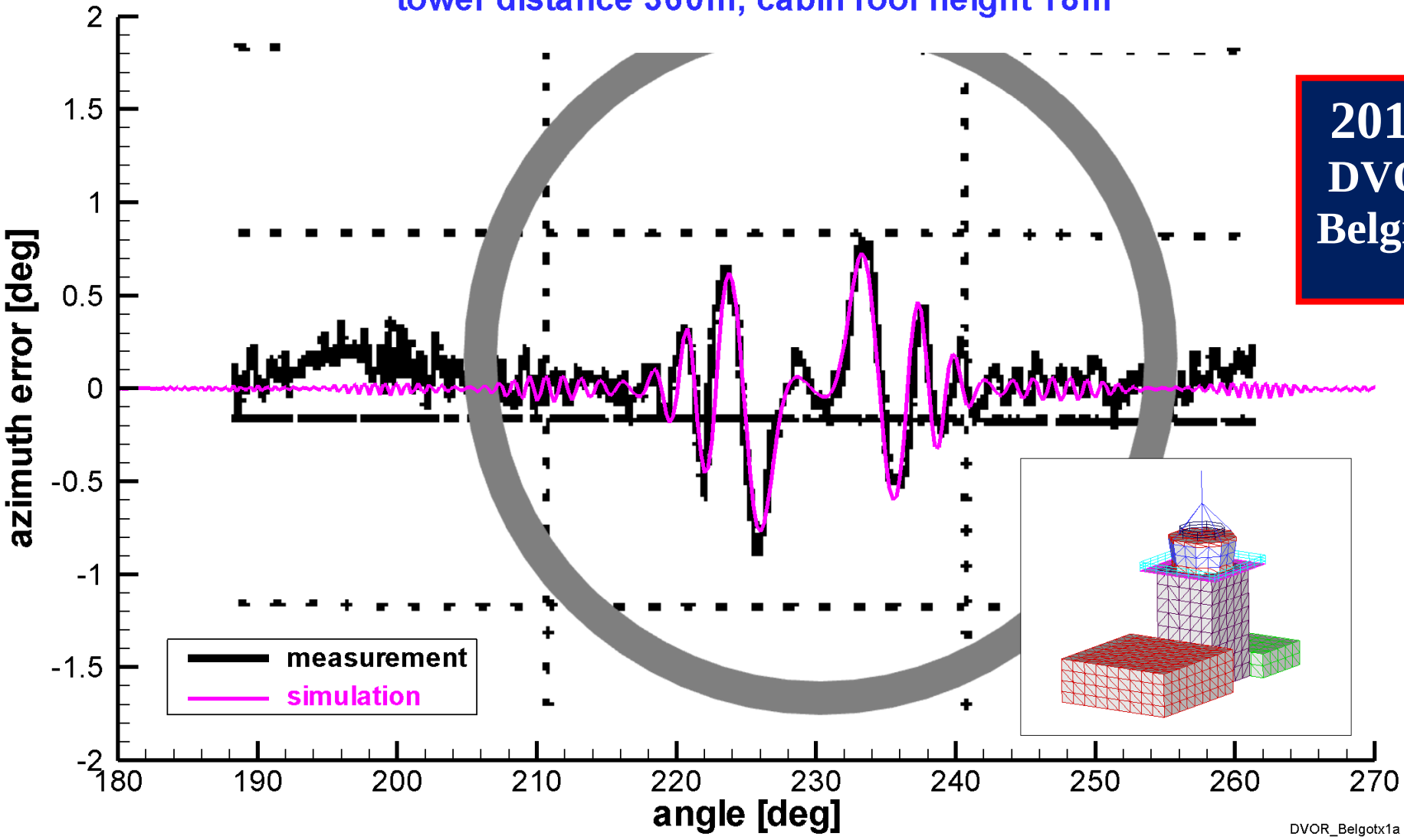
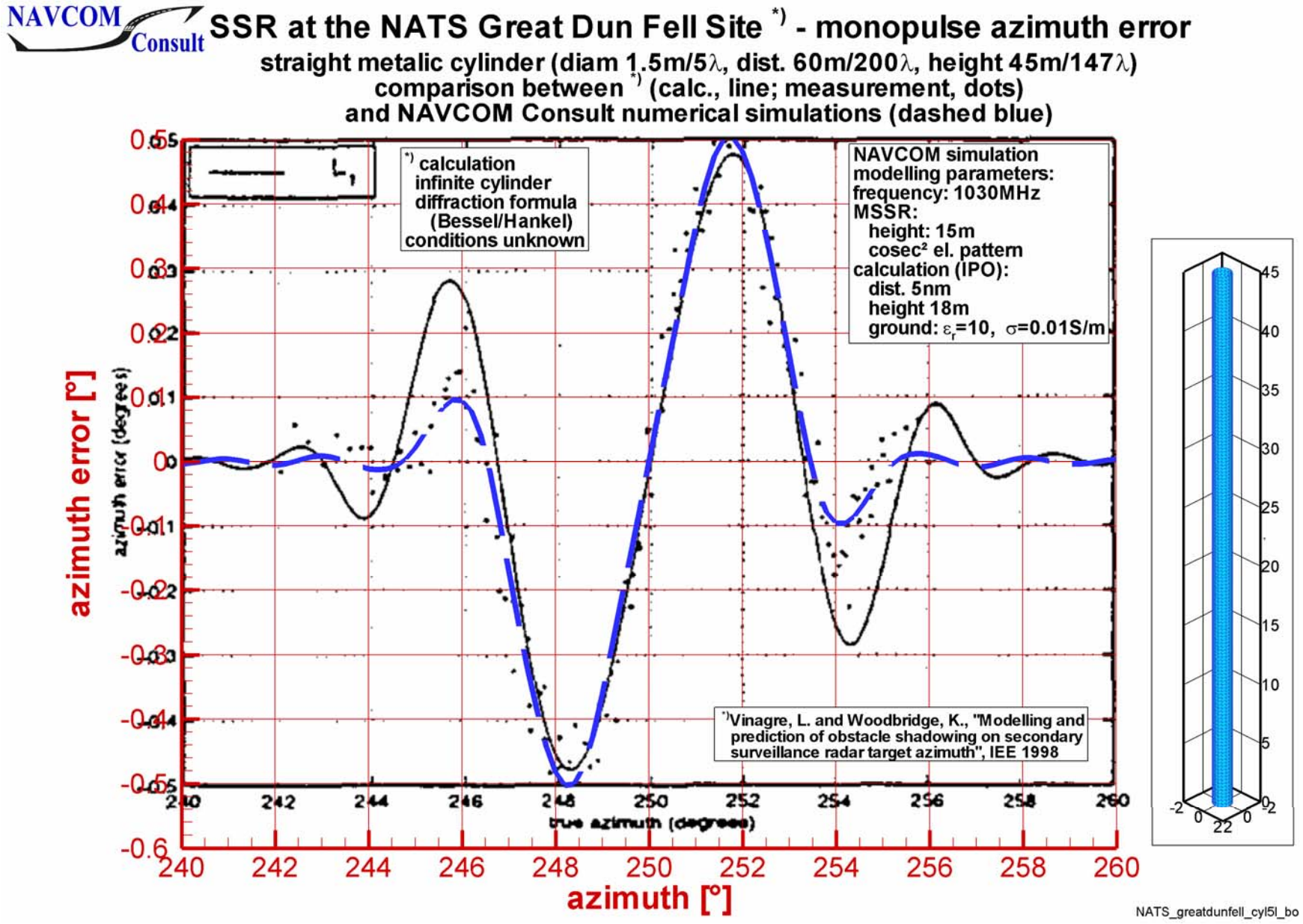
DVOR Belgocontrol - Control Tower

azimuth error, measurement TX1 vs. simulation
measurement by: direction générale de l'Aviation, France
tower distance 360m, cabin roof height 18m



2010
DVOR CVR
Belgien

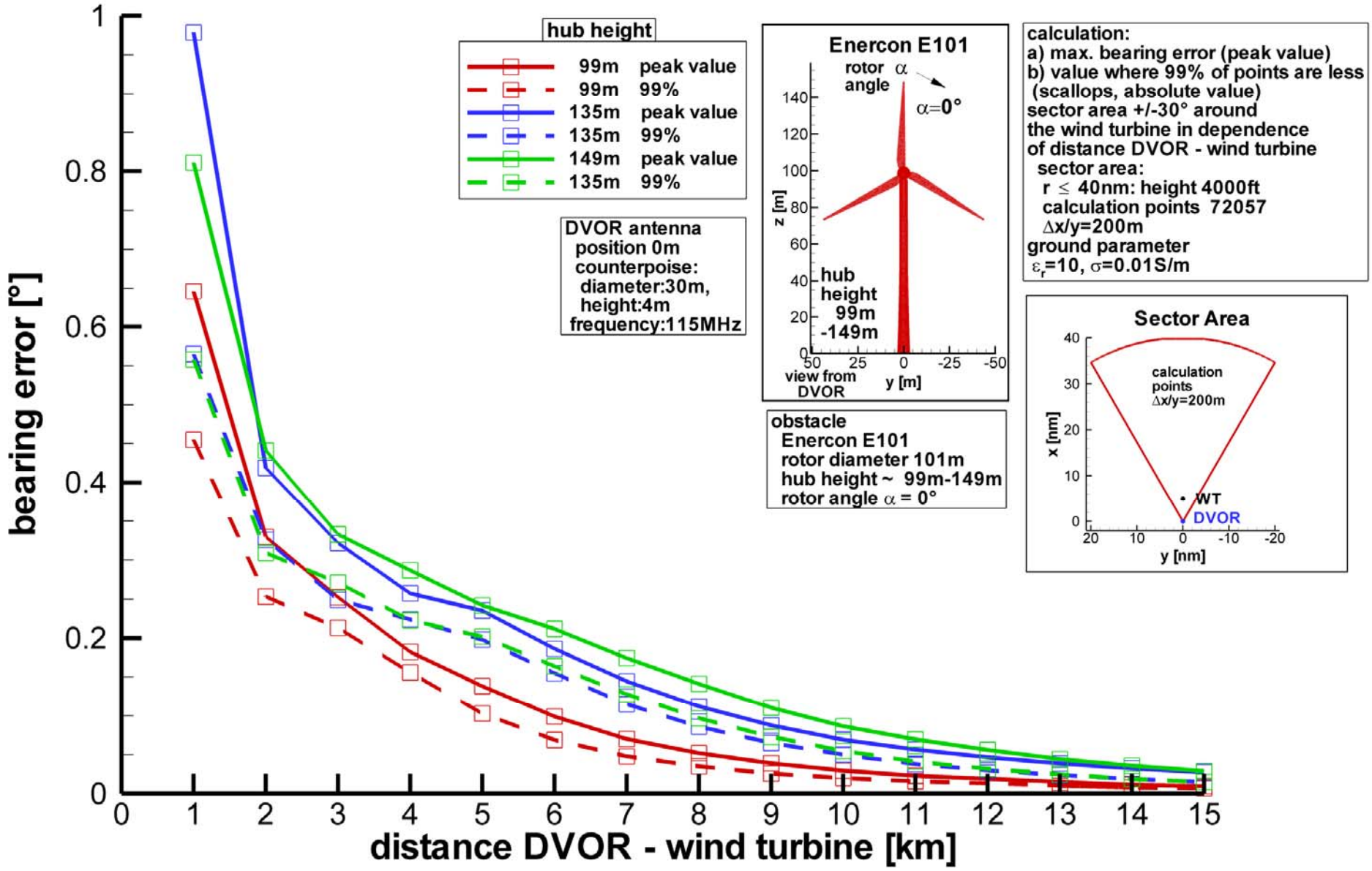
Example : Very close cylindrical tower and MSSR (-Radar)




4 ATC-Radar, 4 DVOR/DME in Hongkong; Planning of the wind farms HEC/CLP
Example offshore
Tai Mo Shan
PSR/MSSR
993
DVOR/DME LKC
45
Beacon Hill
MSSR
477
500
450
>30km
DVOR/DME
69
Sha Chau
PSR/MSSR
CLK
200
180
400
>51km
500
>24km
ICC 484m
Mt. Parker
PSR + MSSR
IFC 406m
10km
Mountains of Lantau island
600
200
400
26km
21km
200
530
>17km
500
450
800
26km
>11km
Ninepin
Islands
DVOR/DME CH
101m
DVOR/DME TD
ca.250m
16km
CLP -
Off-shore Wind farm
67 turbines
6km
200
>22km
>31km
300
HEC
35 offshore
wind turbines
Hmax =133.5m
Lamma
Island
NAVCOM Consult
HKG_lay_CLP_4.dsf 02/12
0
10
20
30

DVOR Disturbance of a Wind Turbine (E101)

Max. Bearing Error of a Sector Area at 4000ft Height - Different Hub Heights



DVOR_maxSec30_E101_nh99-149_a0_4kft

Further Examples - Some Results

⇨ **”Primary Radar” 2D vs MSSR 3D :**

WTs positioned on radials → no advantage IRS2015

“visibility” of WTs by turning blades ←→ no distortion task

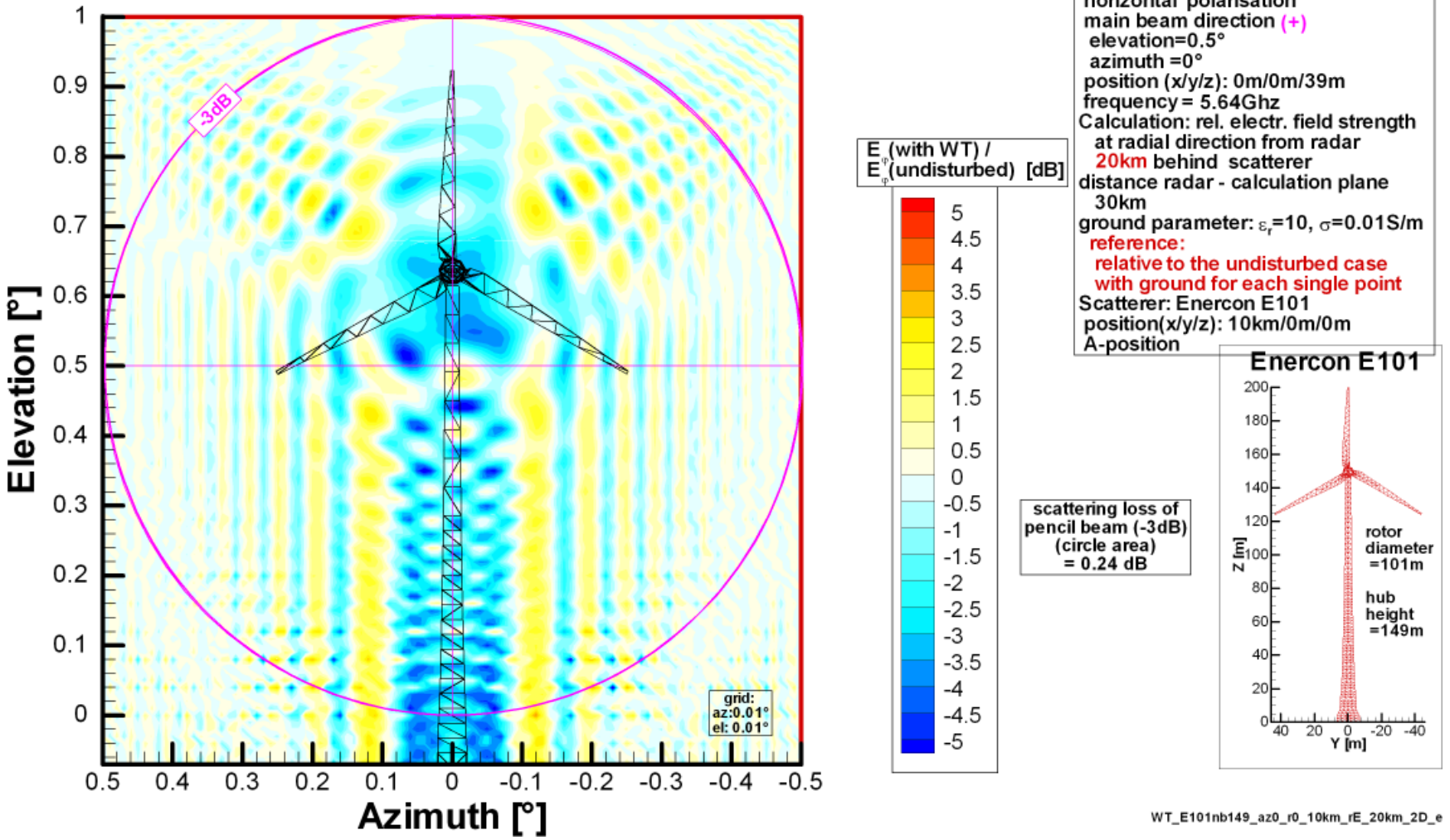
←→ mitigation → “blanking”
“substitution”, interpolation
“range azimuth gating”

Radar is not “blind” behind WTs (some range reduction)

⇨ **Weather Radar : Precipitation error in the back of WTs**
point objects vs volume objects
No relevant errors for realistic distances

Weather Radar WR - Relative electrical Field Strength

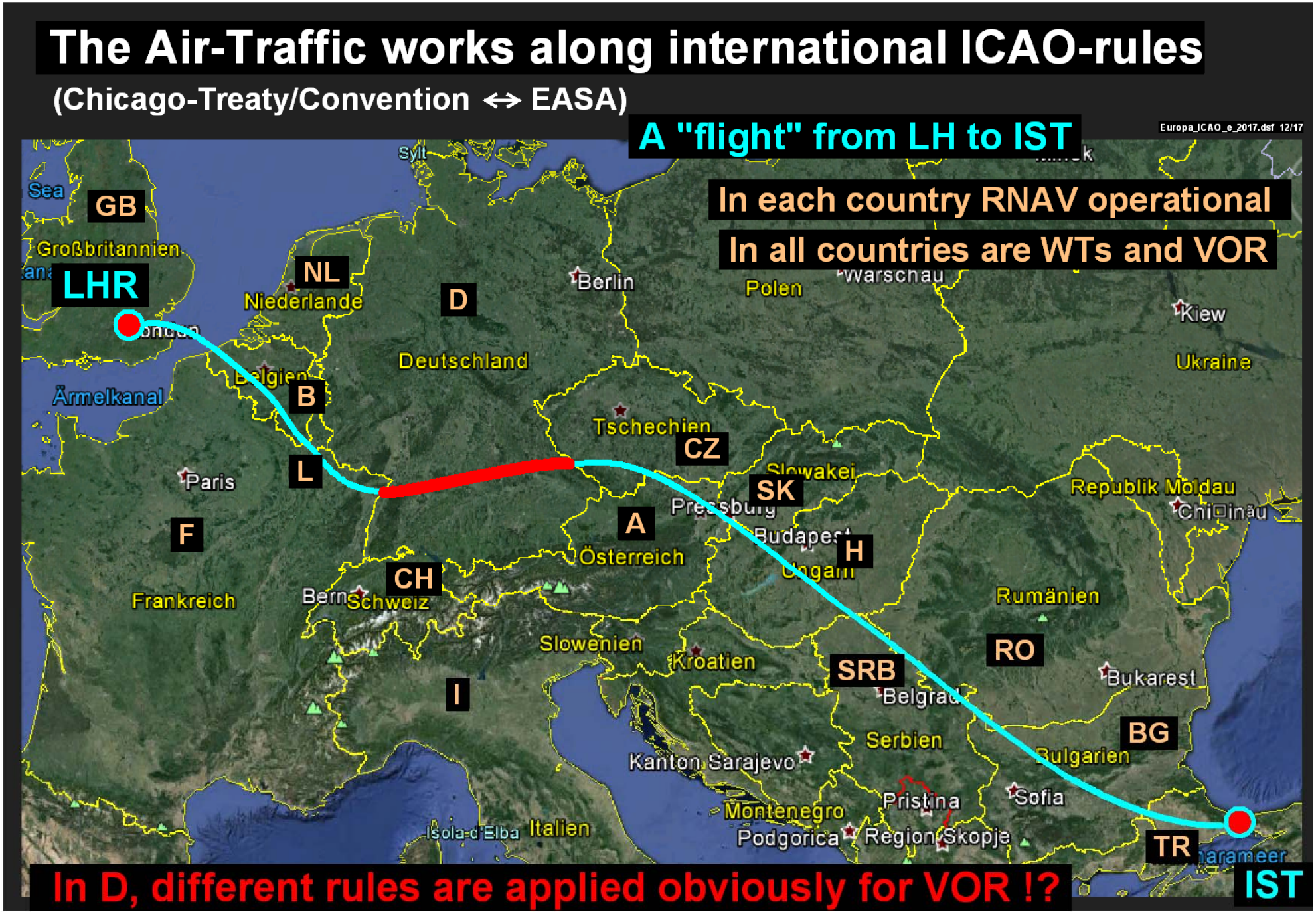
Scatterer E101 at 10km distance



ERAD 2014: Interference field 20km in the back of the WT within the -3dB-main-beam of the WR (distance 10km)

The Air-Traffic works along international ICAO-rules

(Chicago-Treaty/Convention ↔ EASA)



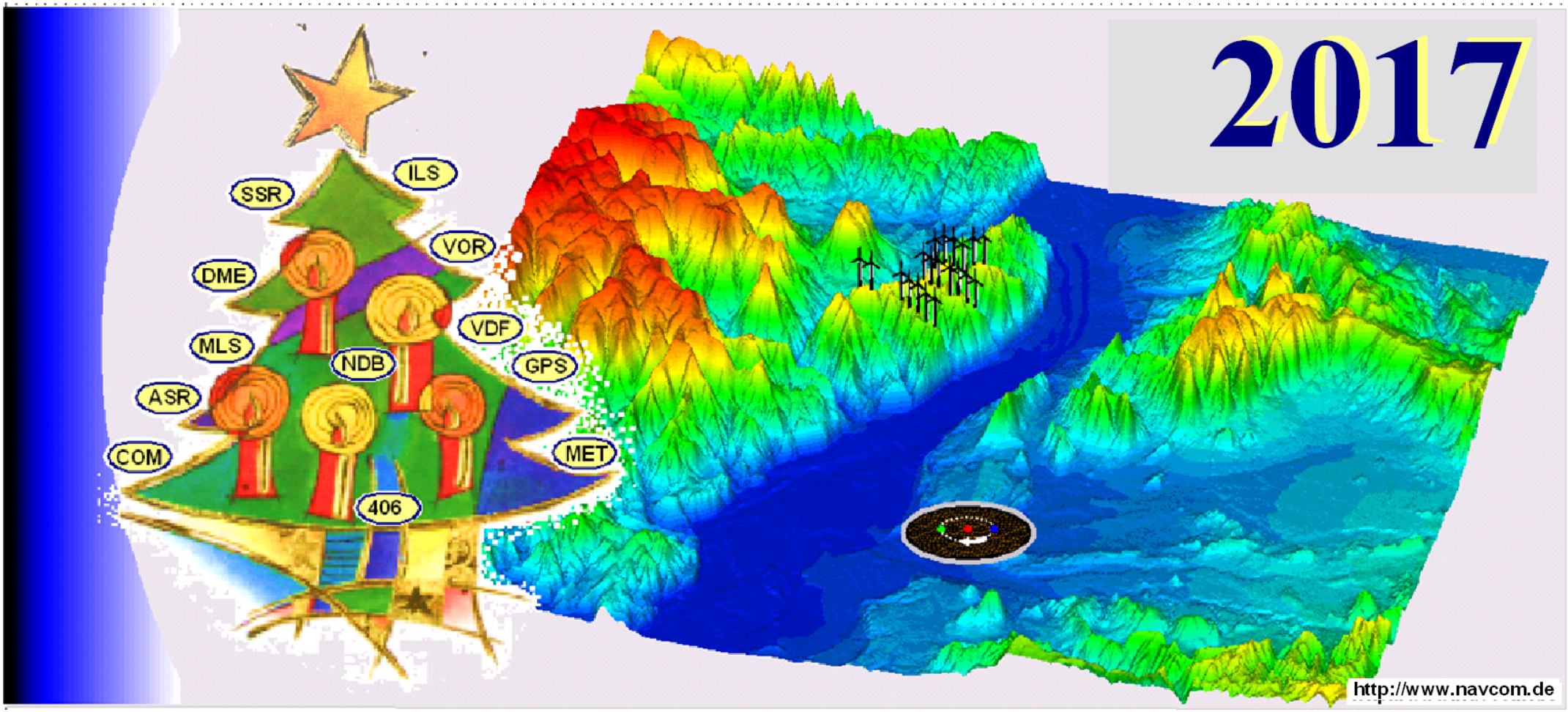
Summary / Recommendations

- ⇨ **Presentation of remarkable discrepancies nat./internat.**
- ⇨ **Presentation of Powerful numerical simulation scheme**
- ⇨ **Validation by agreement with (FI-)measurements**
  And long-term successful operation
- ⇨ **Agreement works as “mutual validation” (“completeness”)**
- ⇨ **Application for almost 20 years by (inter-)national projects**
- ⇨ **Often effects of WTs are over-estimated and exaggerated**
- ⇨ **Meanwhile long-term knowhow and experience for WTs**

THX

Q&A

. 1997 – 2017 20 Years NAVCOM Consult .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