

EMWT19 – ENAC, Toulouse, France

Performant and High-Fidelity Solution for Complex and Large Radar Scene Simulation including Wind Turbines

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High-fidelity Radar Scene Simulation: what for?

Radar simulation of complex environment: what are the main issues

Optimization techniques for efficient simulation

Radar simulation in complex environment, including the sea and ship wakes

Example of an application to Wind Turbines

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RADAR SIMULATION: WHAT FOR?

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**Assessing the performance of radar sensors
in their operational environment**

**Assessing the performance of radar sensors
in various types of environment**

**Assessing the performance of radar sensors
in various types of weather conditions**

**Assessing the performance of radar sensors
on various types of platform**

**Replacing expensive trials
by cost effective and flexible simulation**

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DEFINITION OF THE CHALLENGE

Solution to be designed for assessing the performance of SAR systems in various operational environments and conditions

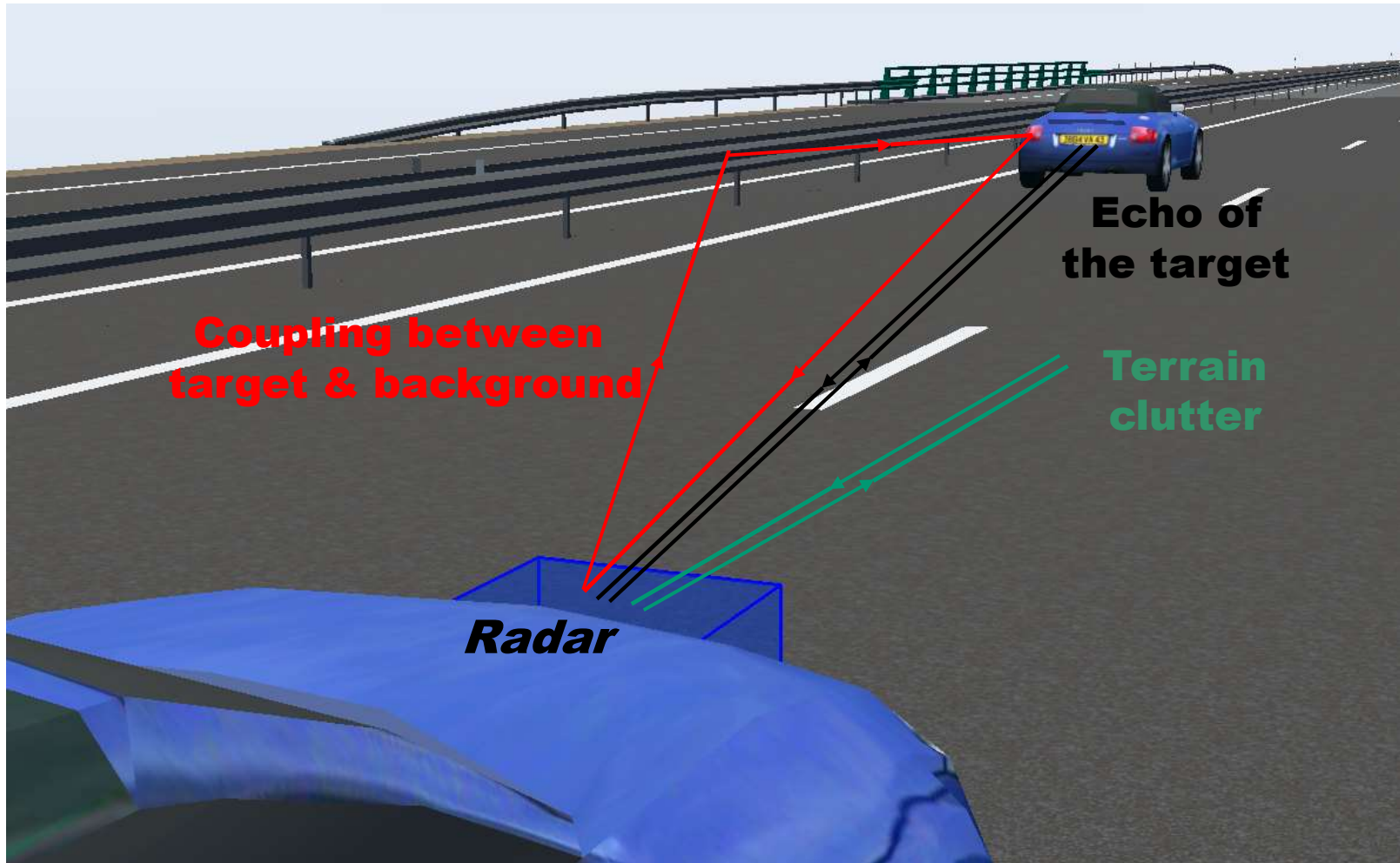
- Can address **high frequencies**
 - Up to 40 GHz
- Can handle **large and very complex scenes**
 - Typically several km x several km
 - Including a large number of targets
- Can handle a **large number of polygons**
 - Typically several millions
 - Convenient for handling high level of detail 3D modeling
- Can provide **high fidelity**
 - Ray tracing + validated physical models
- Can achieve **high performance** simulation
 - Optimized implementation of ray tracing
 - GP GPU implementation
 - Adapted to massive data production

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TOWARD HIGH-FIDELITY

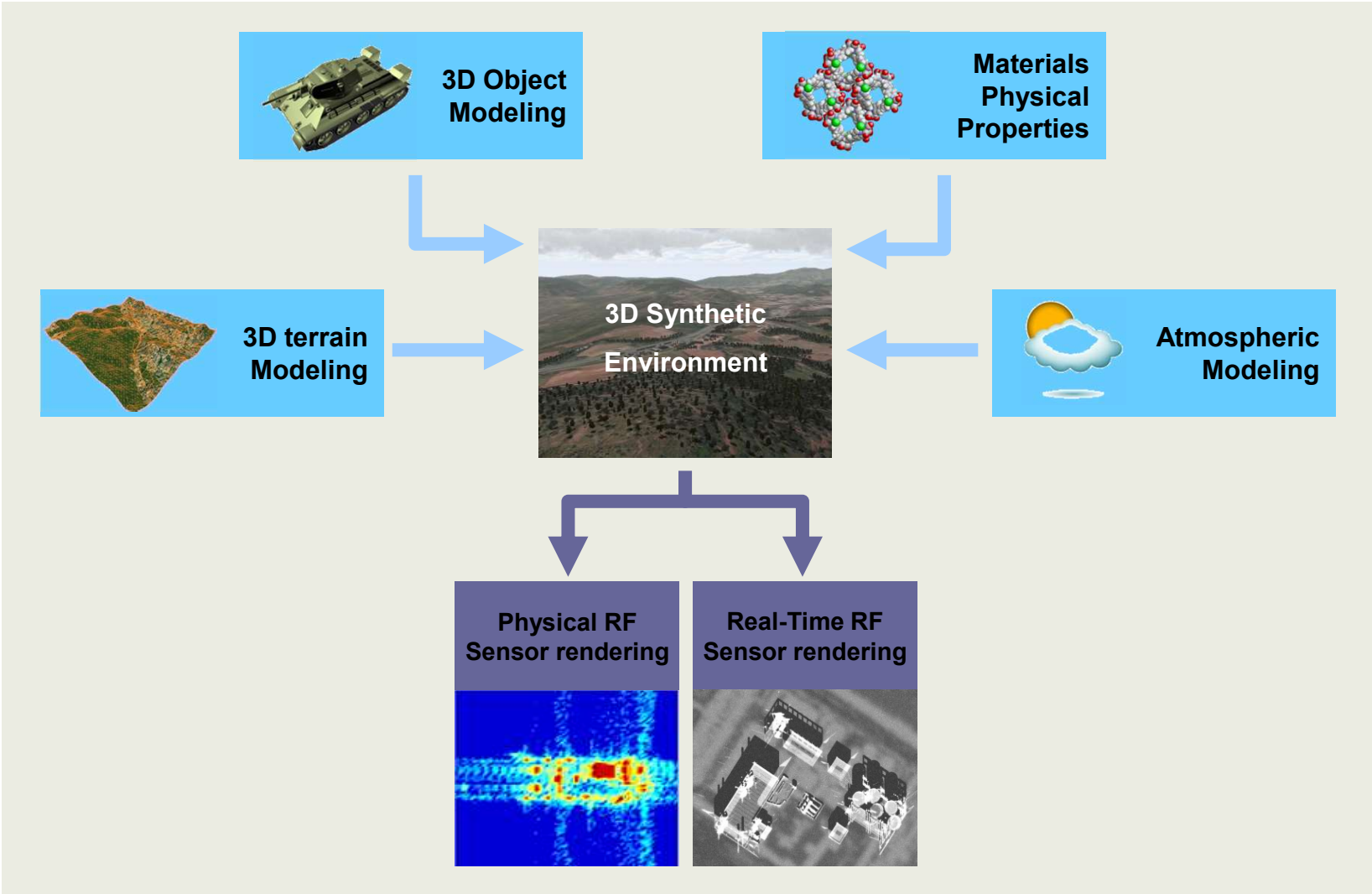
Necessity to consider the whole scene in one run

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COMPONENTS OF SIMULATION WORKBENCH

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CHOICE OF THE RELEVANT RF COMPUTATION METHOD

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- **Full wave methods**

Strictly based on the resolution of Maxwell equations

Often use finite element based solvers since they apply the four Maxwell equations for each finite element, assuming the fields remain constant within each finite element

The mesh sample size is classically of the order of $\lambda/10$

These approaches are restricted in terms of the size of the scene that can be computed

They are not adapted to radar simulation of large scenes

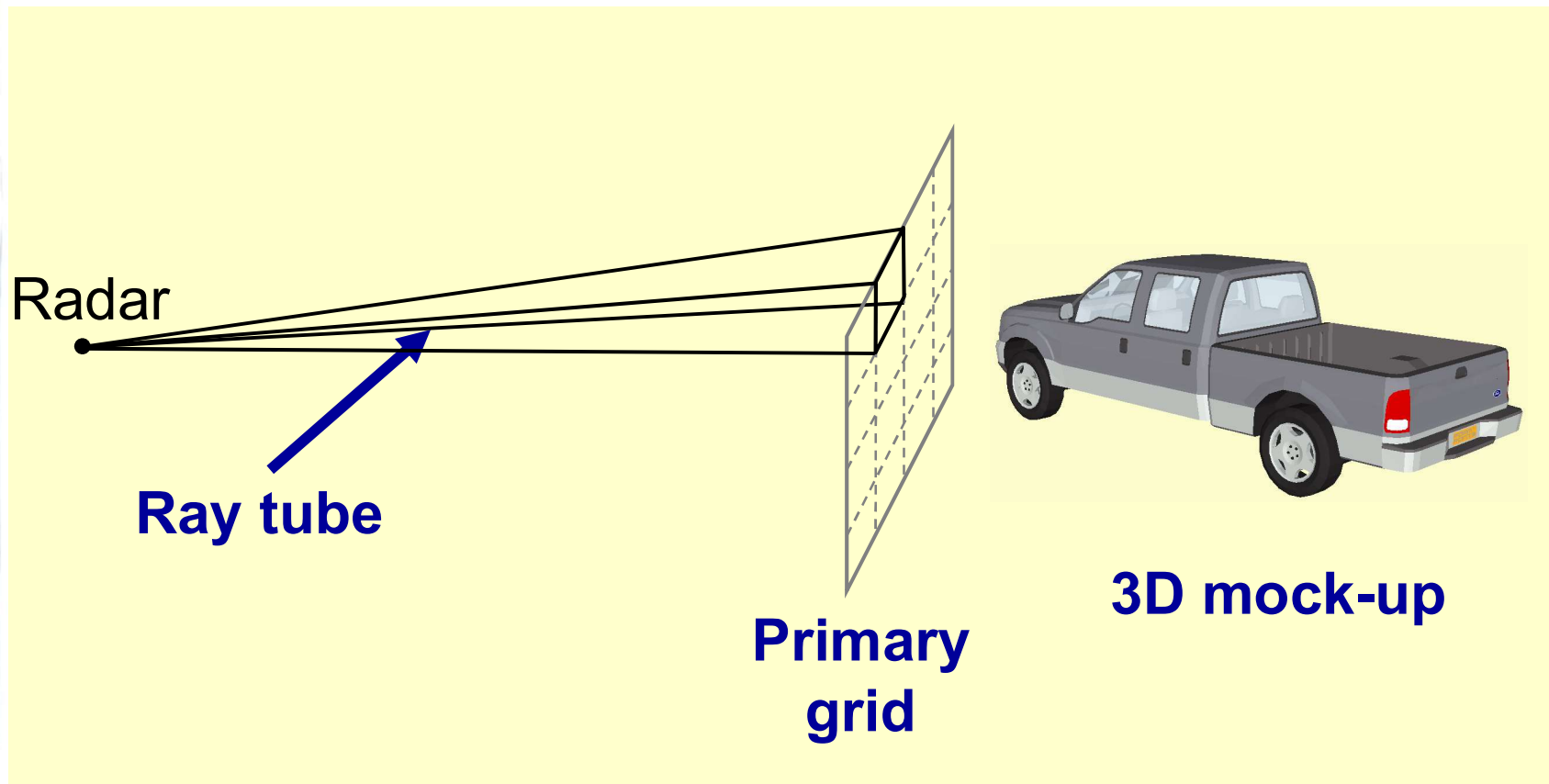
- **Asymptotic methods**

Compute scattered electromagnetic fields at high frequency (the size of the objects is supposed to be large compared to the wavelength)

These approaches are relevant for radar simulation of large scenes at high frequencies since no fine meshing is required

RAY TRACING IN THE 3D MOCK-UP Based on SBR

SBR: Shooting and Bouncing Rays

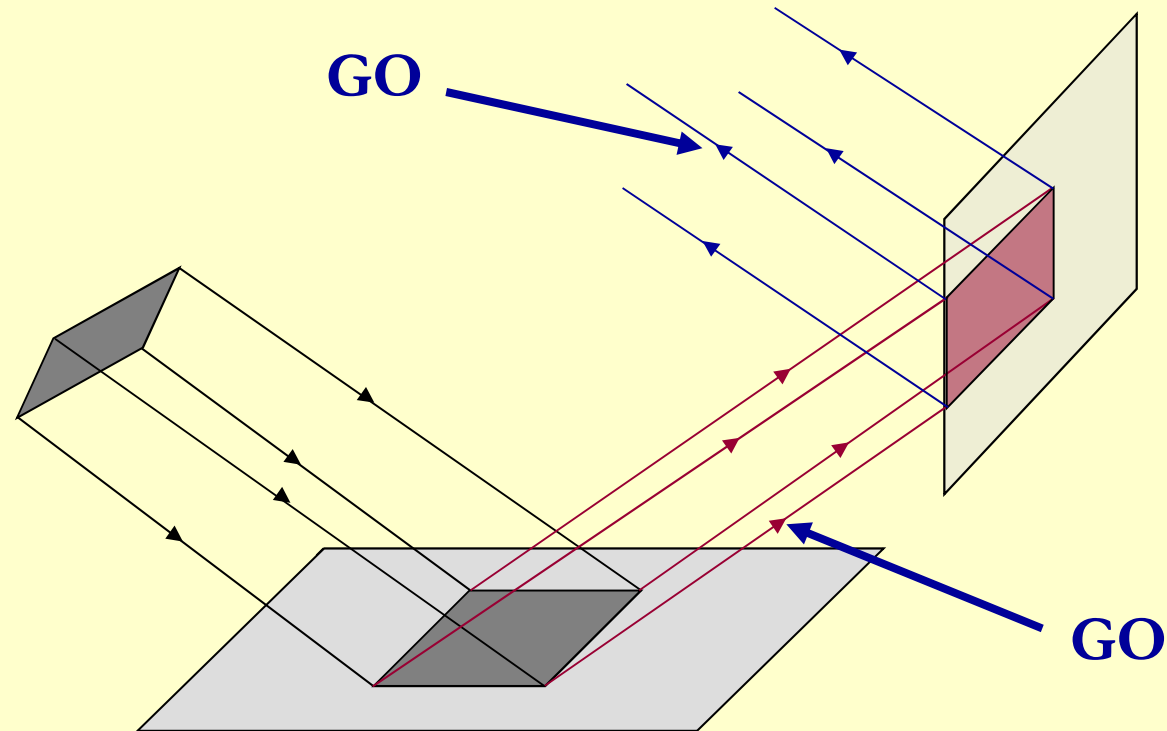


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Multiple Bounce computation based on GO

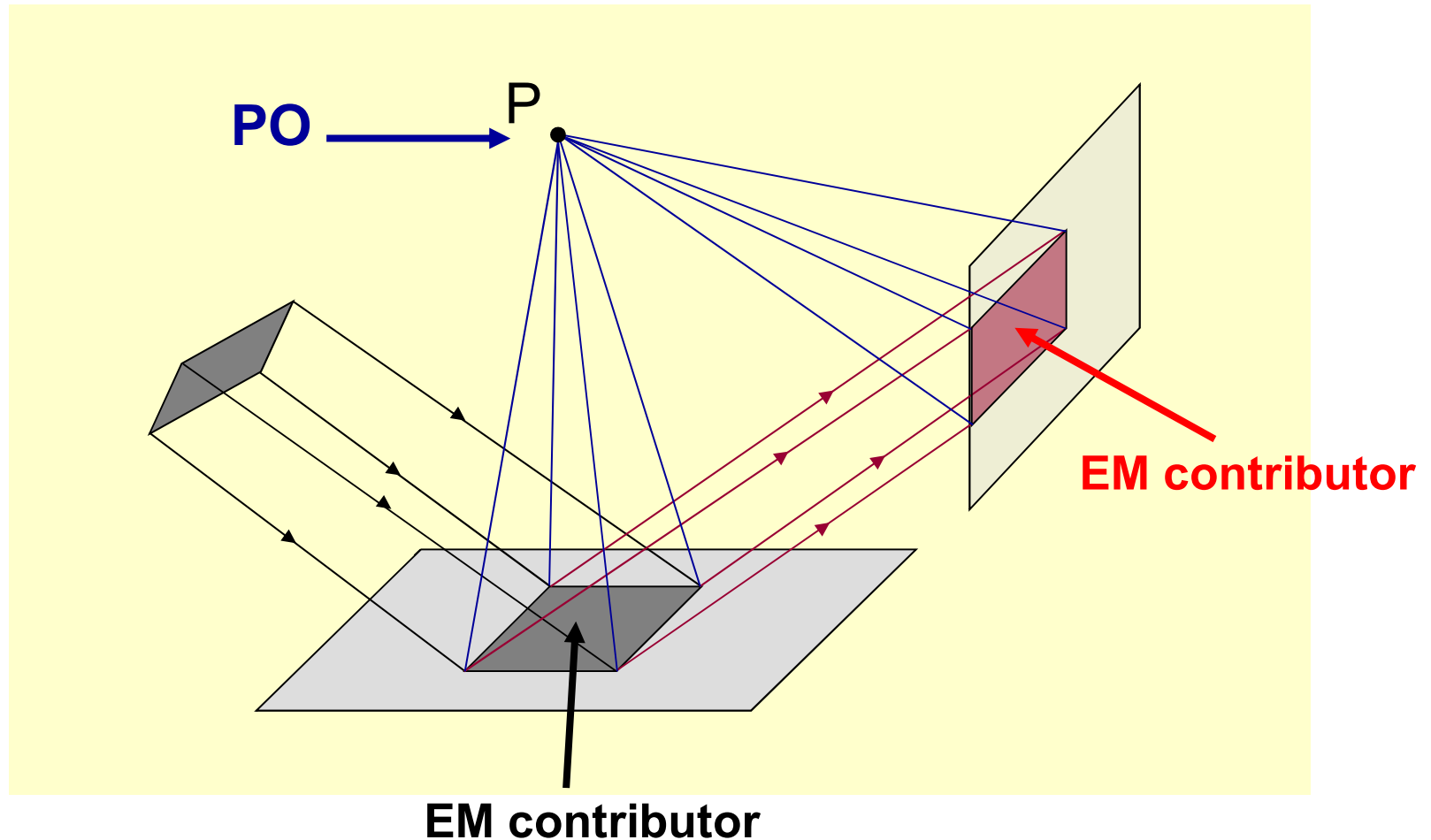
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Interactions between polygons



Shooting and Bouncing Rays (SBR) combined with GO/PO

Scattering to the receiving point "P"



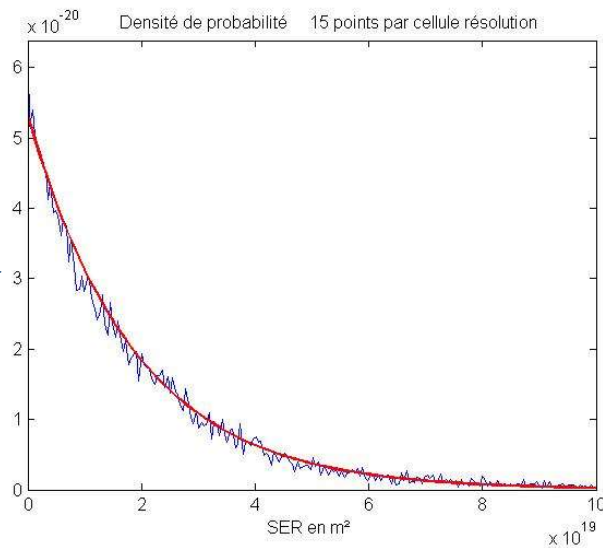
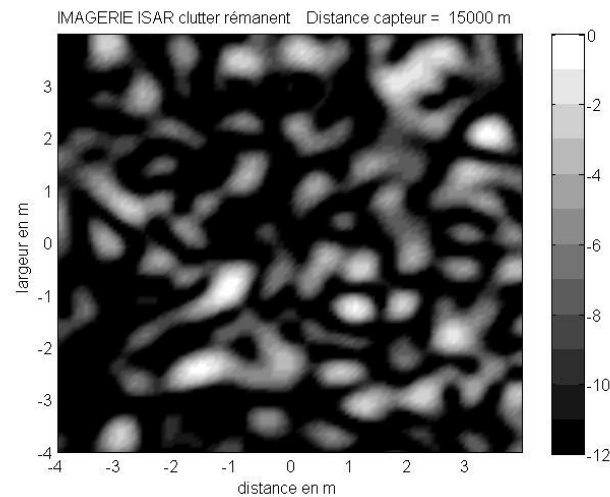
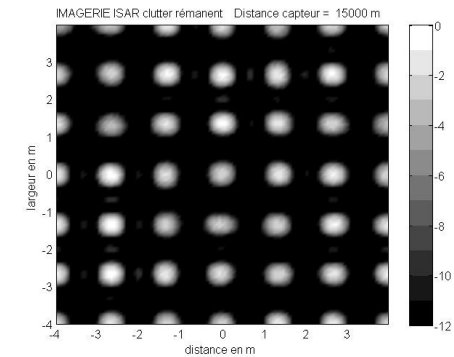
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ONERA inside!

“Coherent” clutter model for terrain and sea rendering

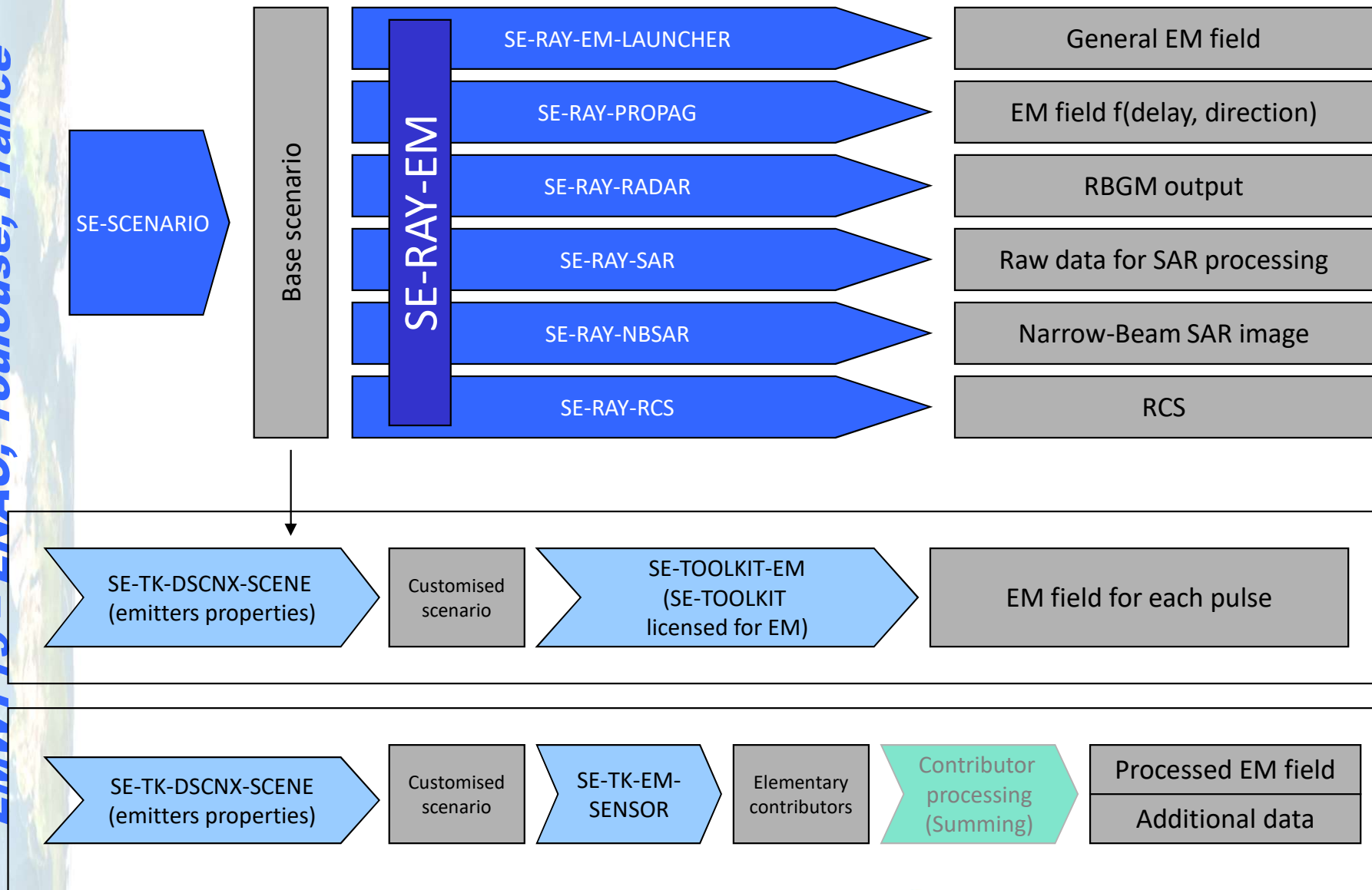
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- ❖ Based on a 2D distribution of scattering centers
 - ❖ All the scattering centers have the same amplitude
 - ❖ Their position is slightly randomised
 - ❖ The phases are randomly distributed
- ❖ Insures spatial coherency in radar/SAR simulation



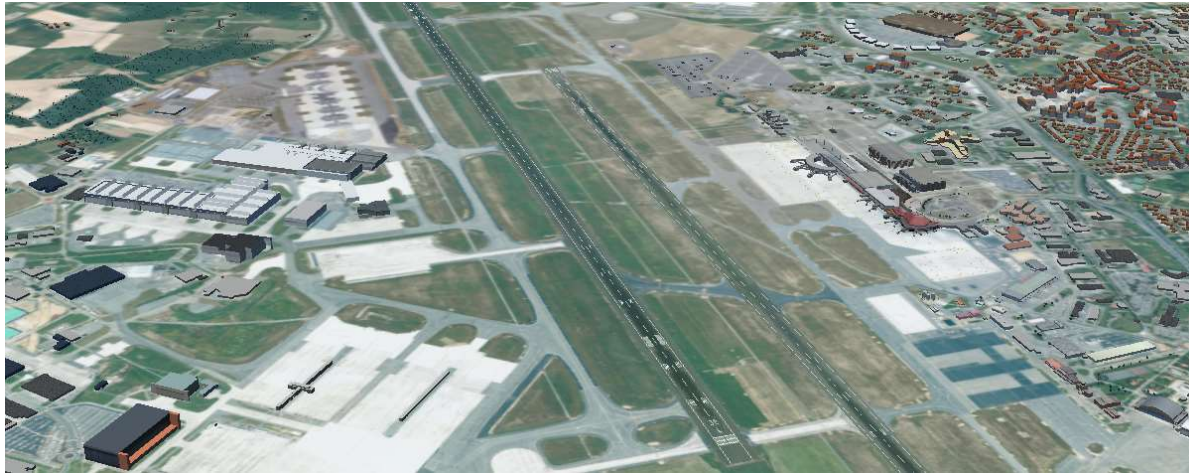
SE-WORKBENCH-RF overview

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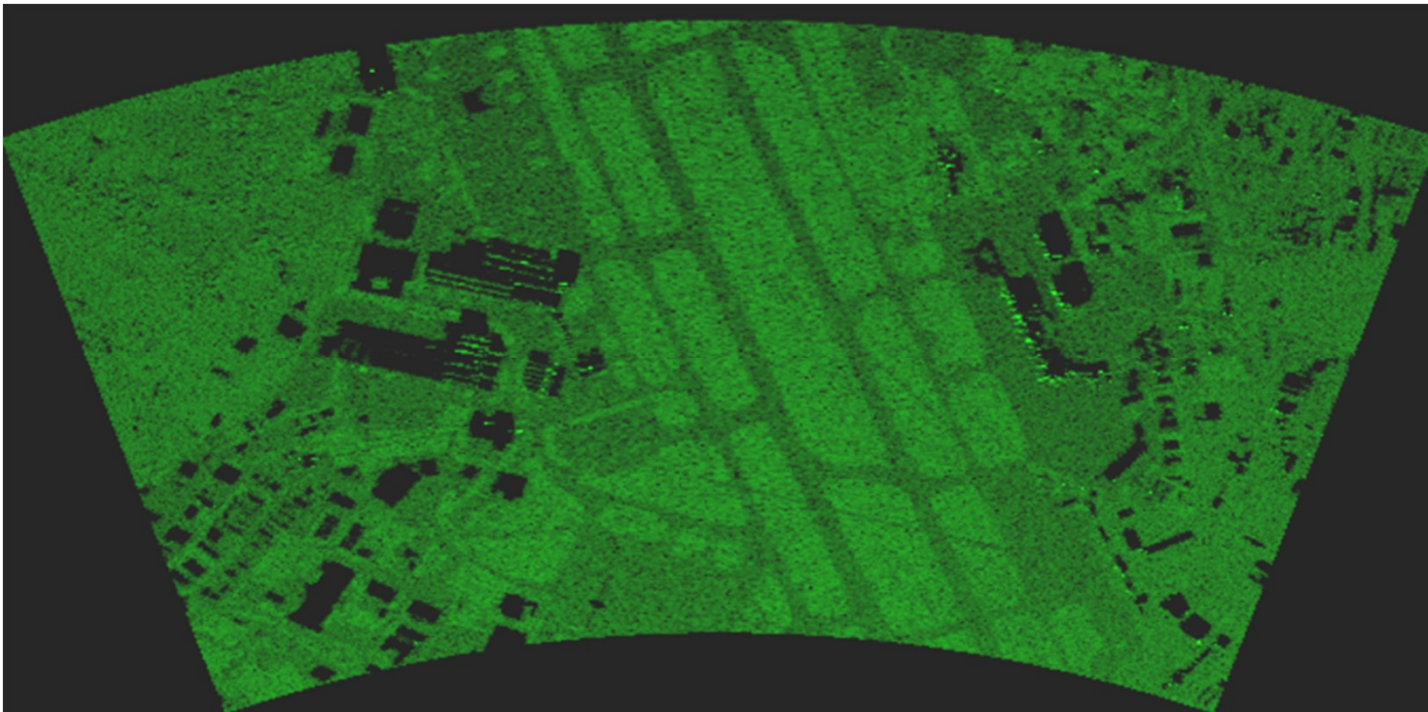


RBGM image generation on Airport 3D DB in X band

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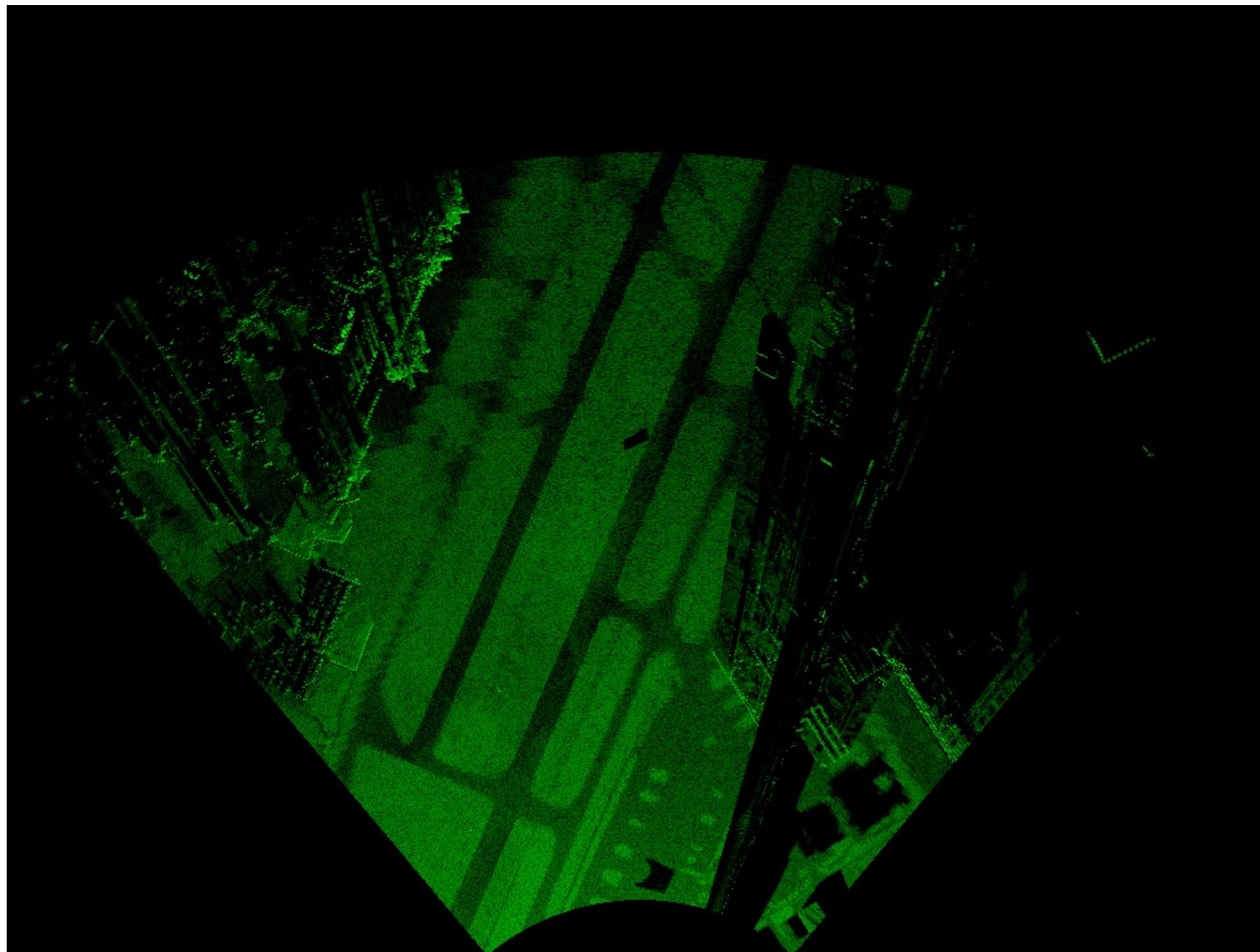
Airborne Radar



RBGM image generation on Airport 3D DB in C band

Ground Radar

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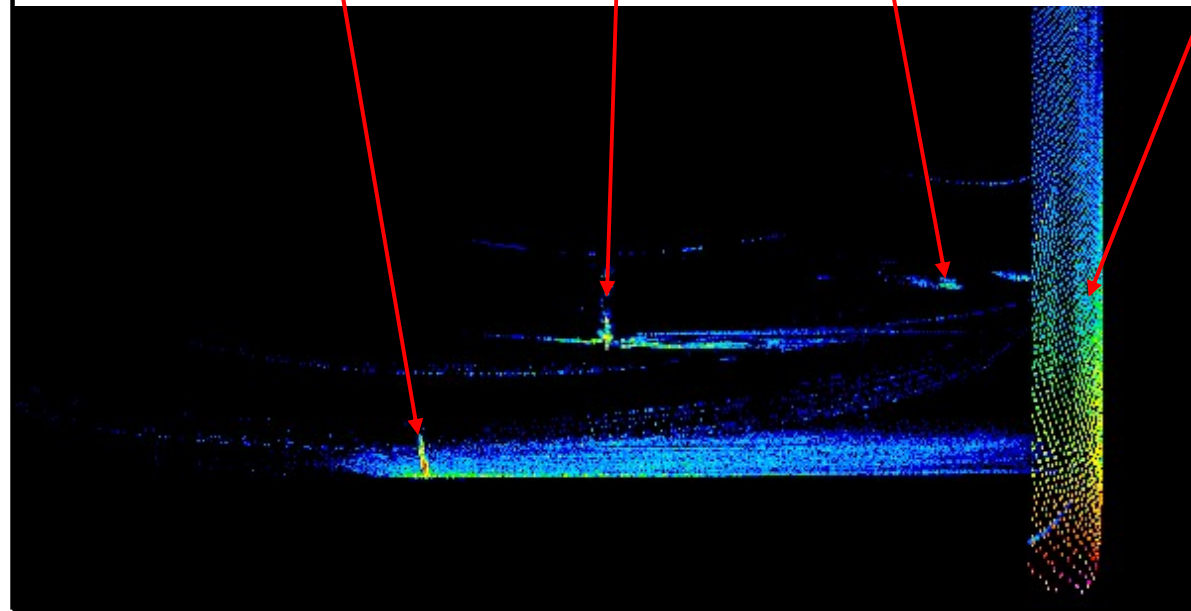


RADAR SIMULATION IN THE AUTOMOTIVE DOMAIN

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Range

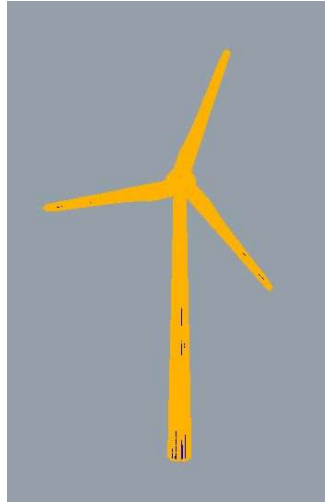
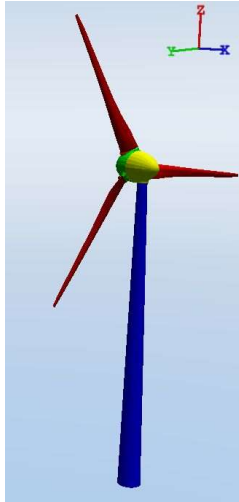


Terrain clutter

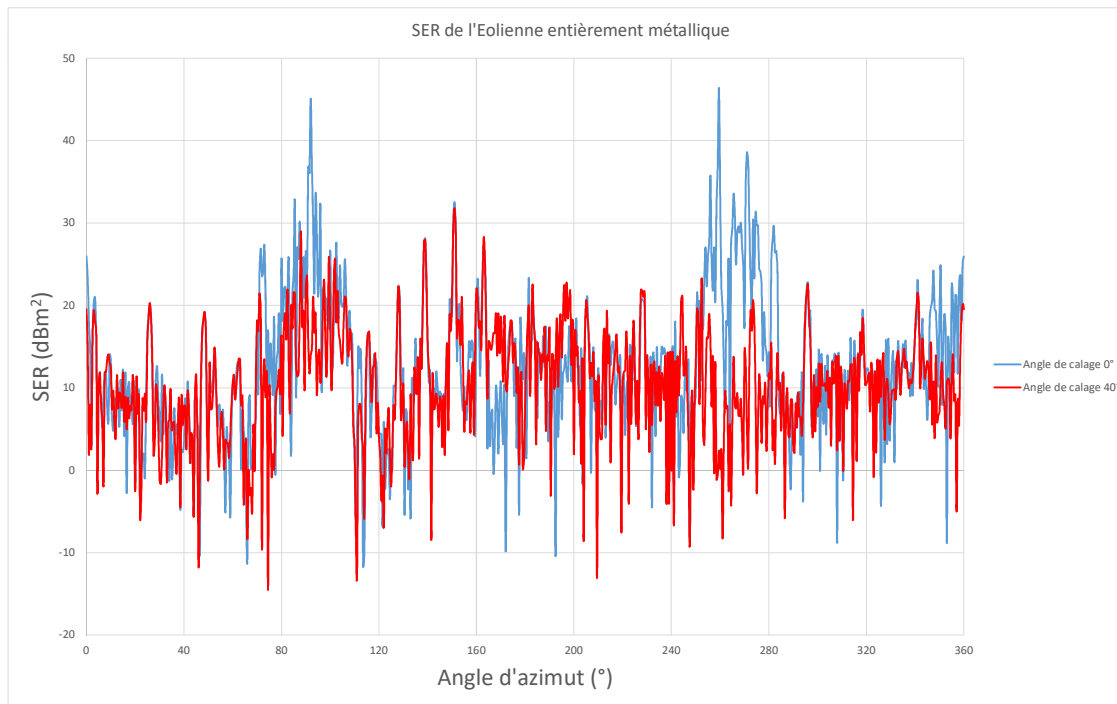
Doppler

RCS of Wind Turbine

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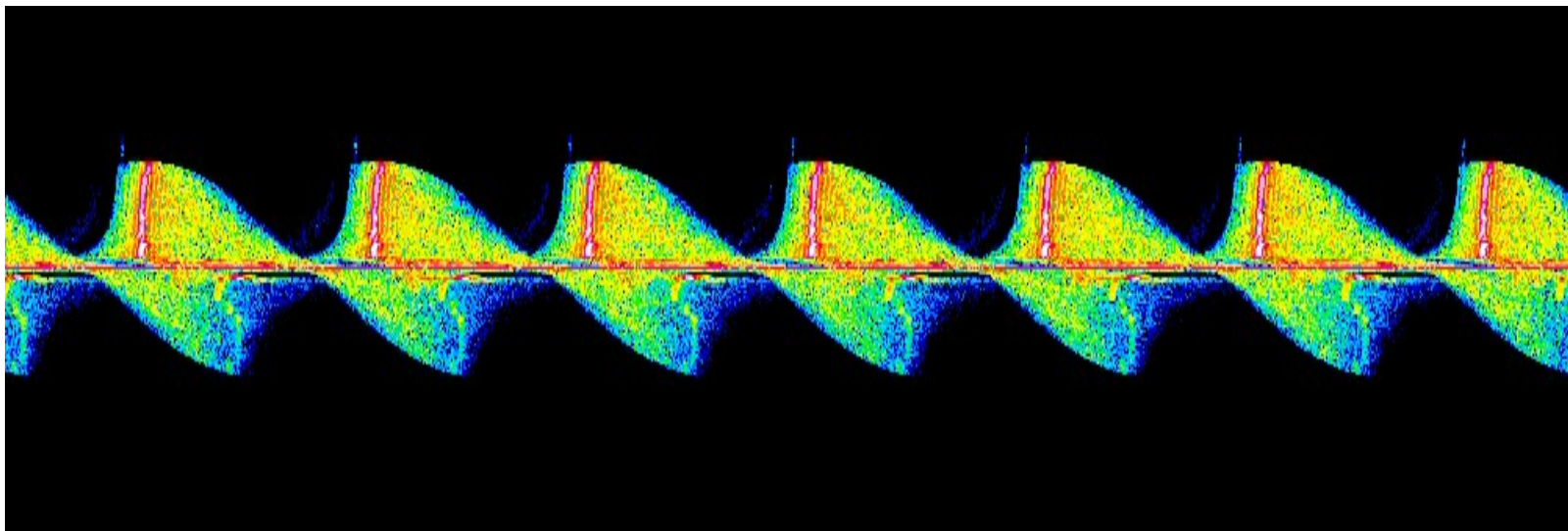
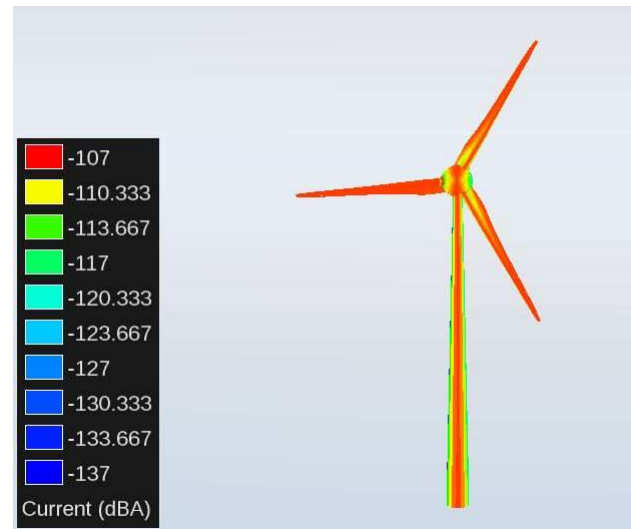
3D model made of
10,400 polygons



RCS depends on
wedging angle

Doppler signature of Wind Turbine

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Validated models

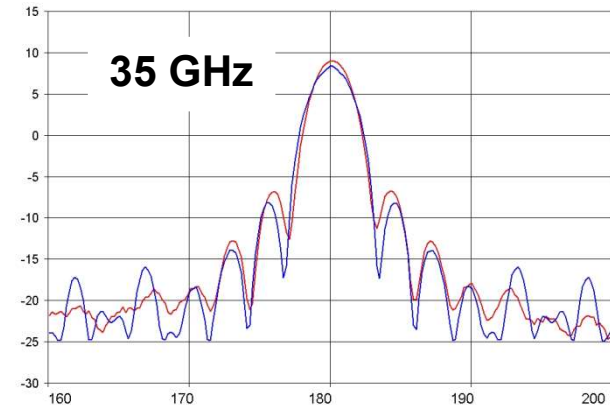
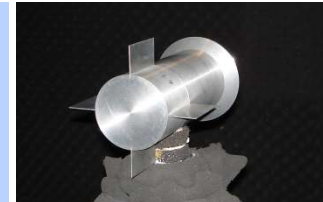
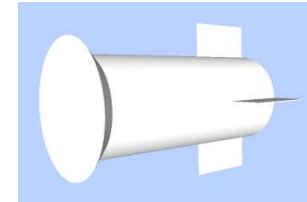
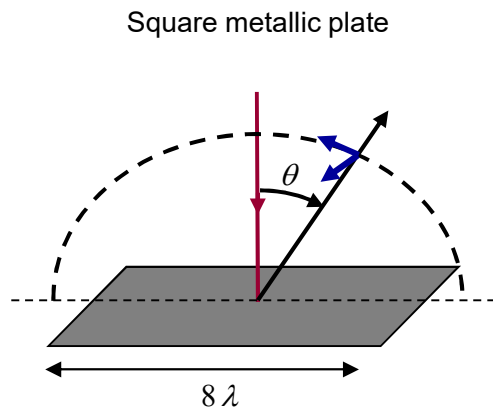
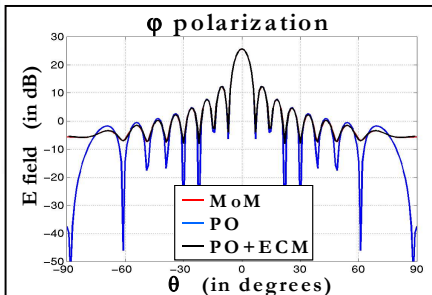
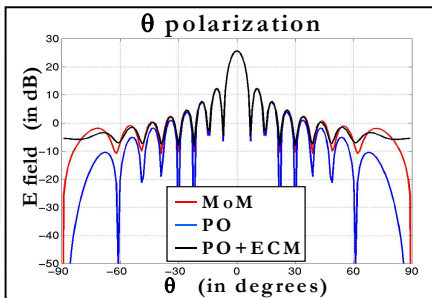
❖ Theoretical validation

- ☞ Development of physical models
- ☞ General modeling and simulation knowledge
- ☞ Elementary tests and validity assessment

❖ Validation by experiments

- ☞ DGA/CELAR experimentation
- ☞ TUBS and AIRBUS on Toulouse Blagnac airport
- ☞ NATO SET in ATR domain

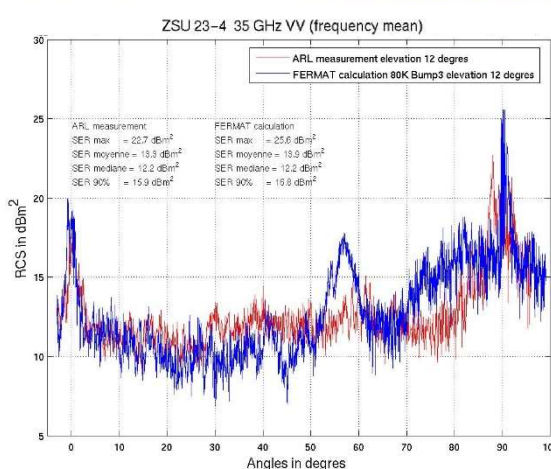
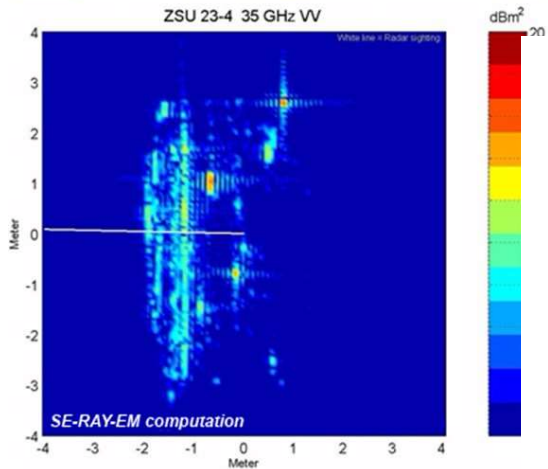
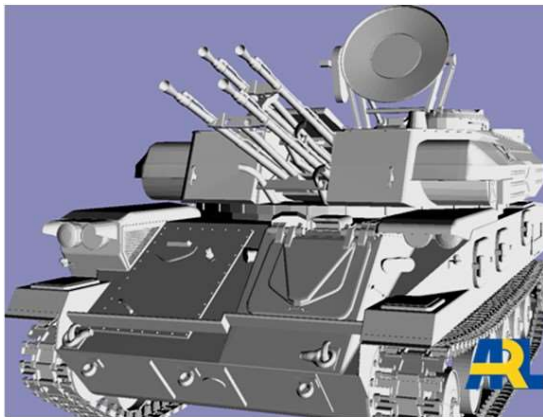
❖ Full validation dossier delivered



Test by comparison with real operational EM measurements

Comparison of ISAR images simulated using SBR + asymptotic method with a set of measurements provided by ARL on a test military vehicle

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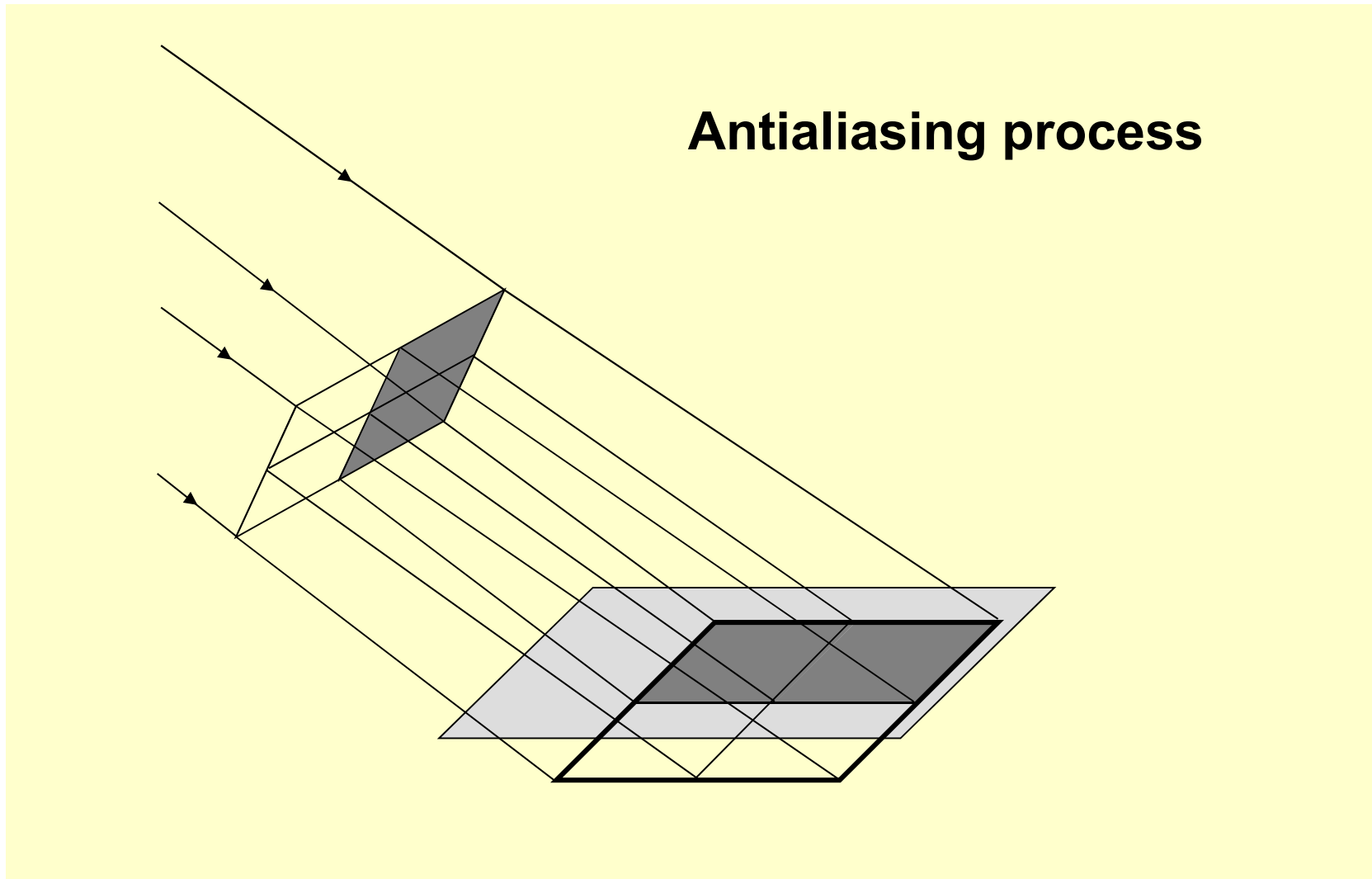
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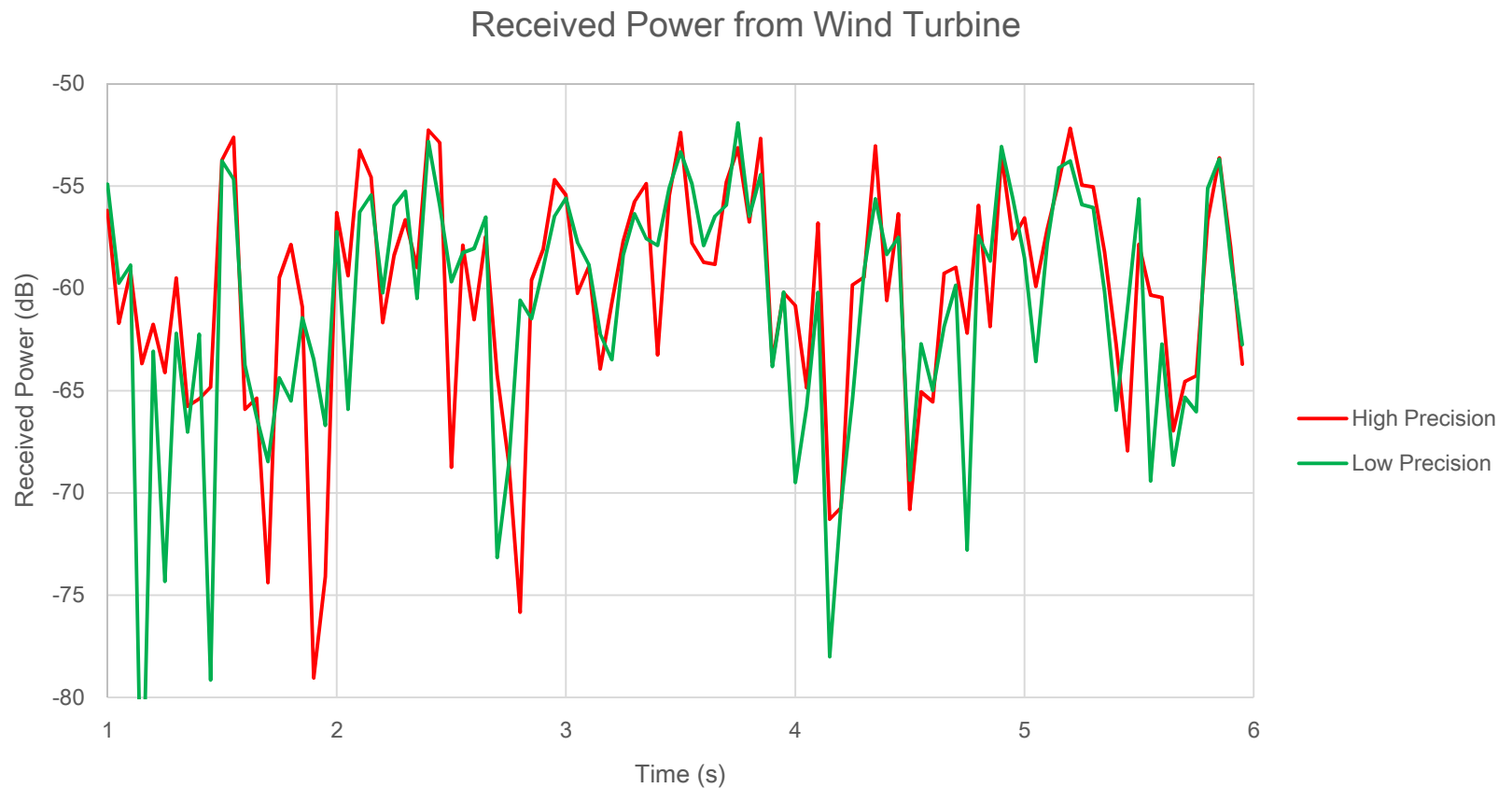
Example of an application to Wind Turbines



Antialiasing process is adaptive: applied if necessary

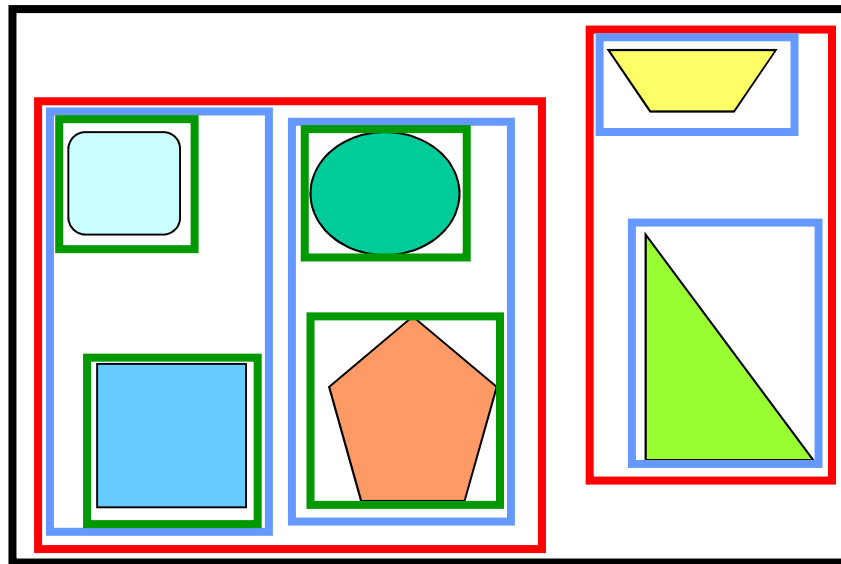
Trade off between precision and computation time

Antialiasing parameters are used to adjust

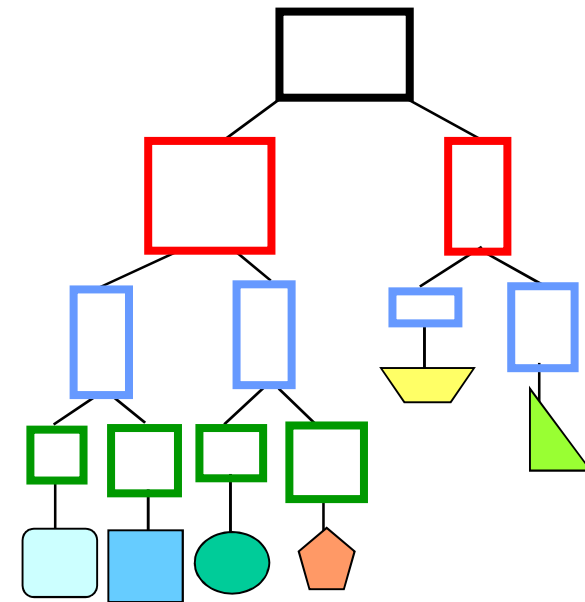


The low level precision computation is 20 times faster with 0.2 s for one RCS value

- **Bounding Volume Hierarchy (BVH)**



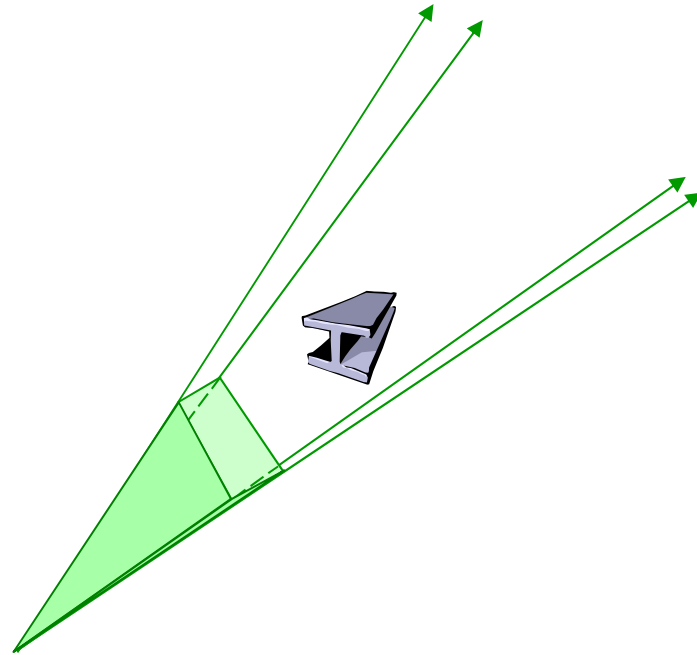
Scene



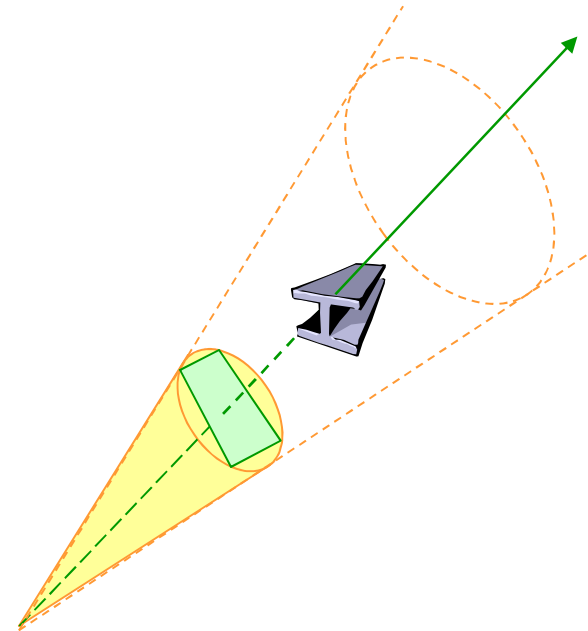
BVH

NEW RAY TRACING APPROACH: CONE TRACING

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**Standard punctual sampling:
the object is not detected
because no ray of the
beam has intersection with it**



**New volume sampling:
the object is detected
because it is in the volume
of the cone**

OPTIMIZED IMPLEMENTATION

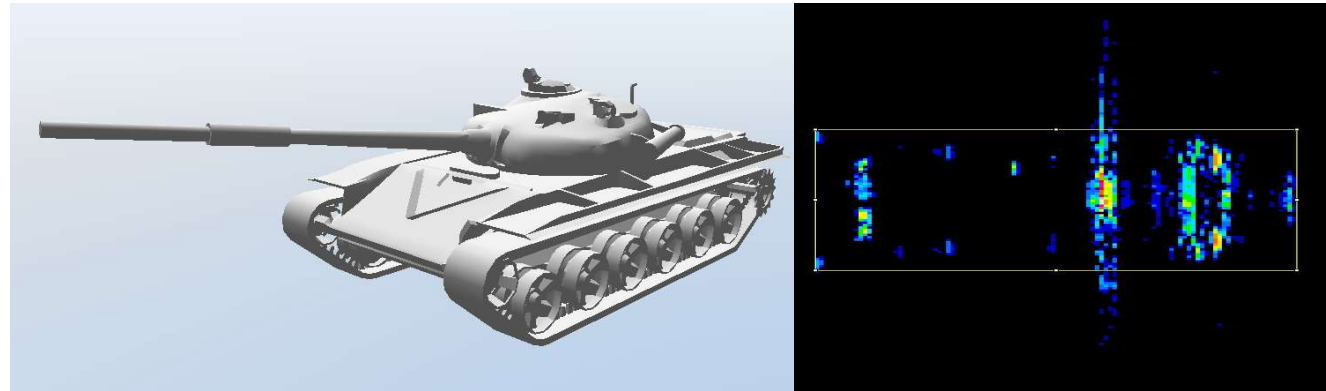
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- Beams are traced using **cones** instead of individual rays
- **Neighbour** cones are processed **independently** which is **very** interesting for **parallelization**
- We use **serialisation** of the subdivided beams in order to **control** the **number** of beams
- Geometrical contributors are **shared between frequencies** for applying EM models leading to performance improvement in **multi-frequencies** computation
- Our **new** implementation only uses **double accuracy** computations when it is **absolutely** necessary, mostly in the **computations** that involve the **phase** of the electromagnetic signal

EXPLOITING THE GP GPU TO ACCELERATE COMPUTATION

Using new GP GPU capabilities of PCs and laptops

- Based on CUDA technology
Nvidia dedicated language that enables to take advantage of the GPU for massively parallel approach

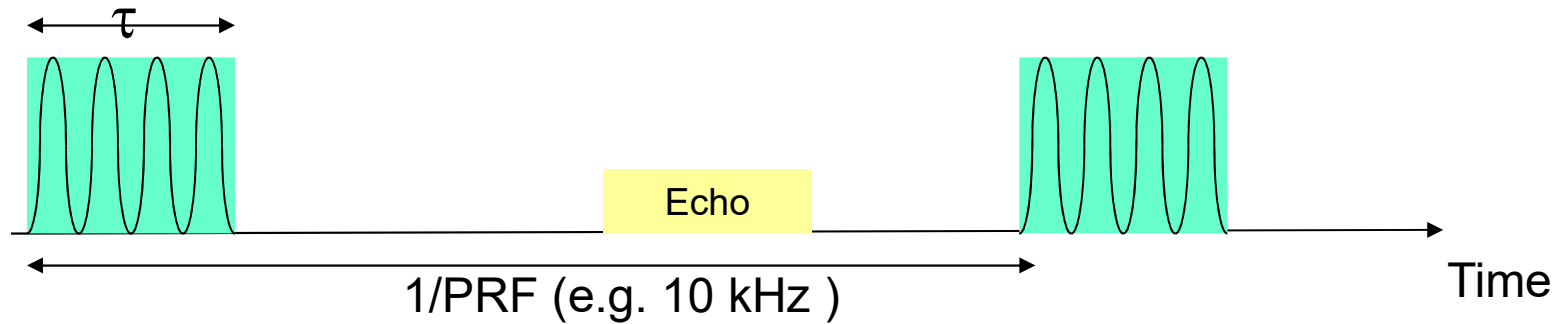


Times in seconds

	Standard Core I7	Standard Core I5	CPU Core I7	CPU Core I5	GPU GeForce 540M	GPU GeForce Titan
Mono-frequency	16.28	12.17	7.49	5.60	0.86	0.111
151 frequencies	109.00	80.40	97.85	70.4	7.62	0.735

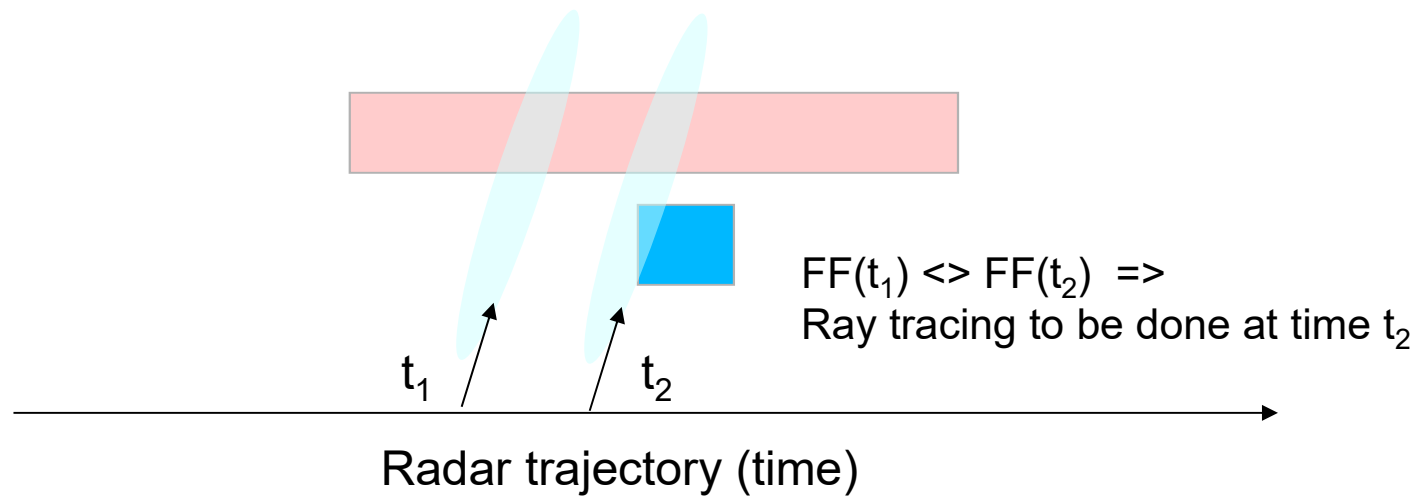
OPTIMIZATION OF RAY TRACING RHYTHM

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Ray tracing is normally done at PRF rhythm

For optimization, it can be done more slowly, depending on the FORM FACTOR variation



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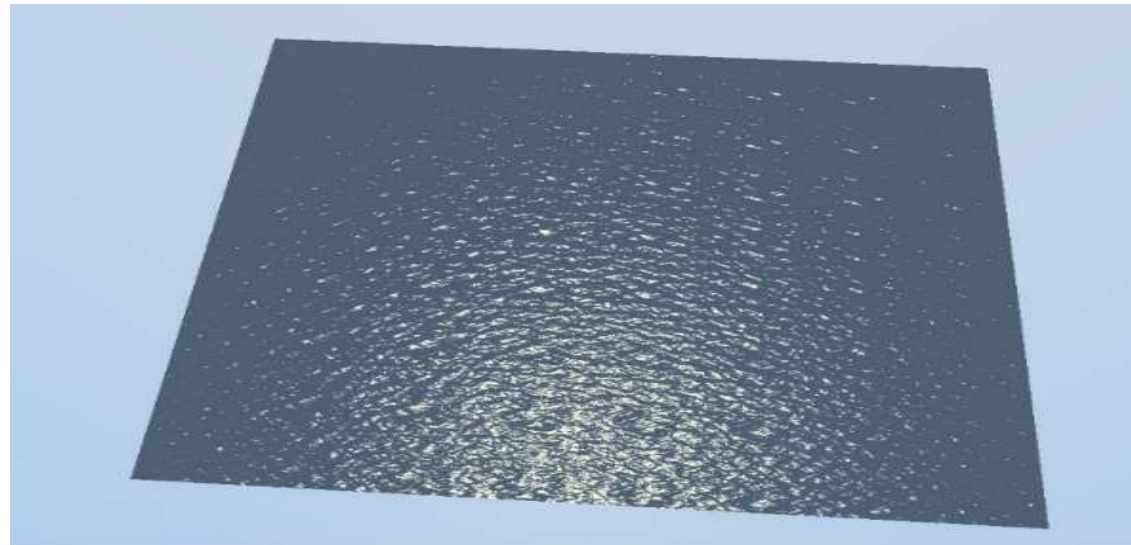
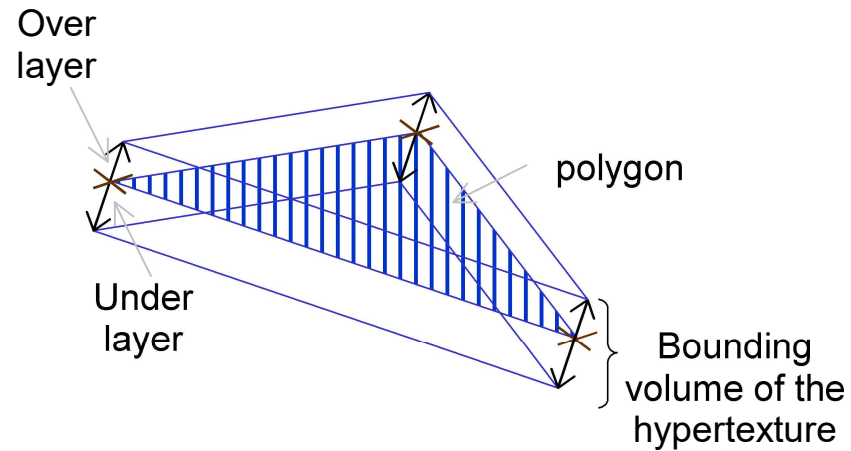
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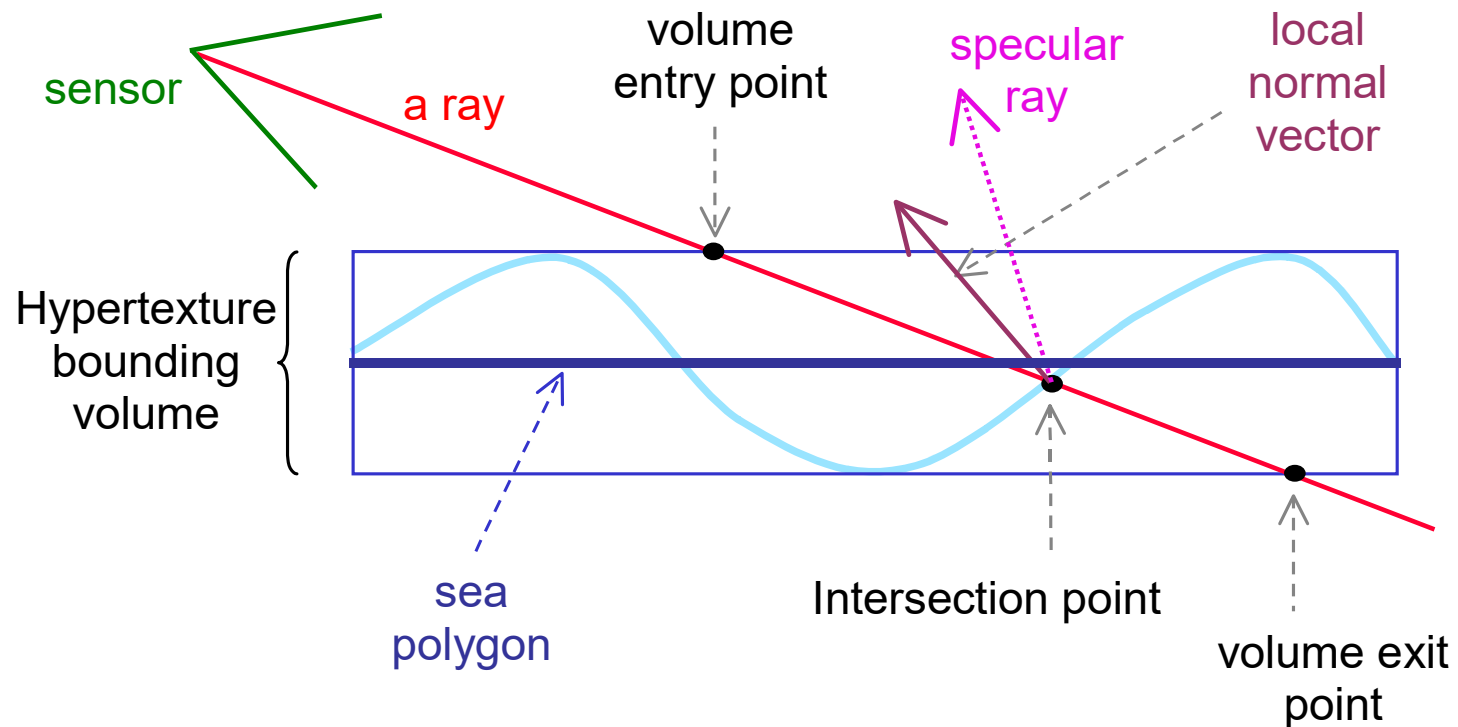
SEA modelling as a dynamic surface

Based on Hypertexture derived from Wave Spectrum(s)



SEA rendering based on Ray Tracing

The hypertexture is considered for evaluating the local incidence and the shadowing at grazing angle



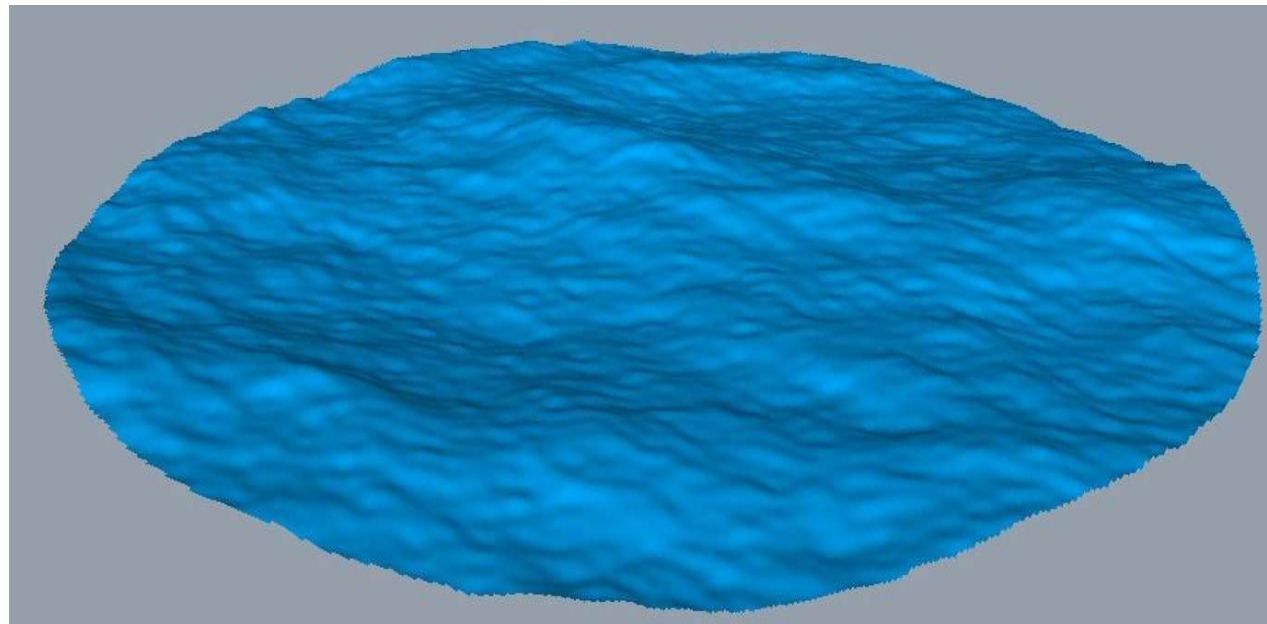
Physical Characterization of the Sea Water

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The sea water is considered as both a dielectric material and a bistatic scattering surface

The reflection coefficients are modified by the sea roughness

The Bistatic Scattering Coefficients (BSC) are derived from GO/PO computation of a 3D sample of the sea surface generated based on the sea wave spectrum



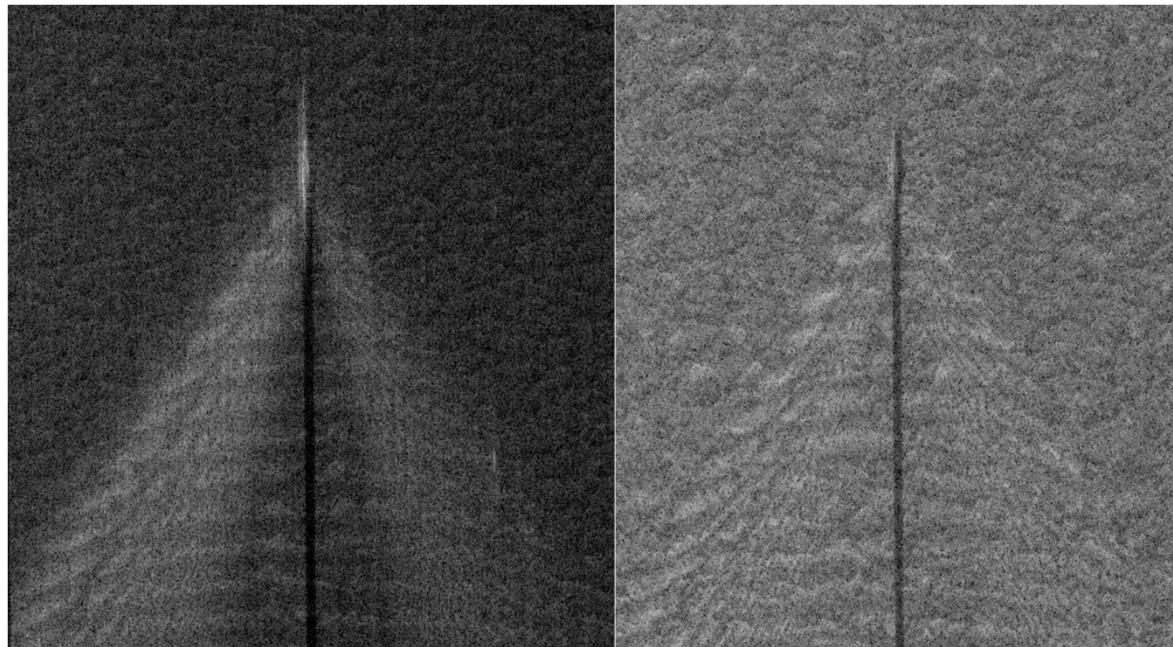
Physical Characterization of the Ship Wakes

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Two types of wakes are considered: the Kelvin wake and the dark water wake

The Kelvin wake is implemented as a 3D local wake height map deformation which is consistent with hypertexture profile

The dark water wake behind the ship is considered as a zone with lower sea state to simulate the flattening of the sea surface due to the movement of the ship at the sea surface



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Scenario with One Wind Turbine very close to the radar

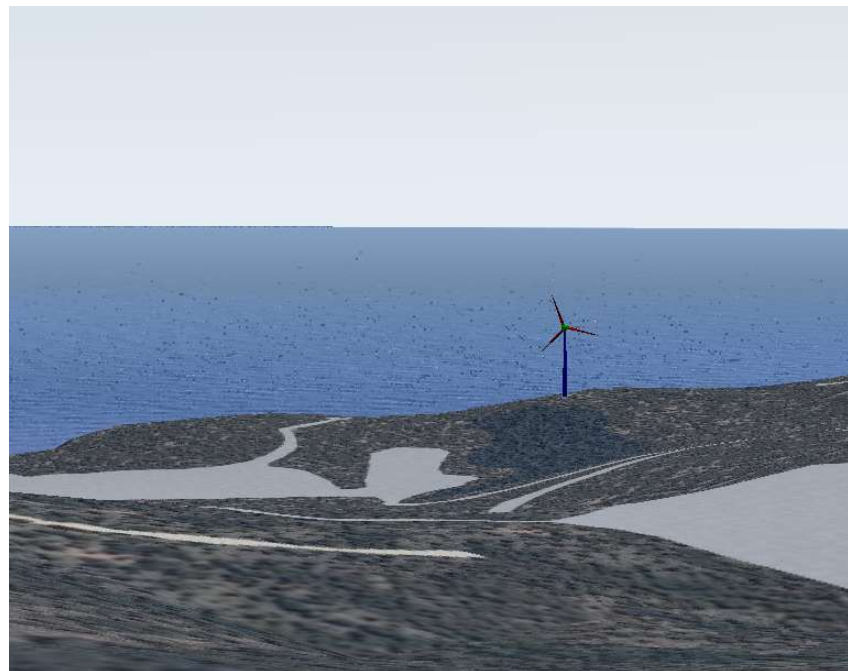
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Target = Speed Boat



Wind Turbine & Target in background



Wind Turbine at Sea Shore

Distance between radar and WT = 1 km

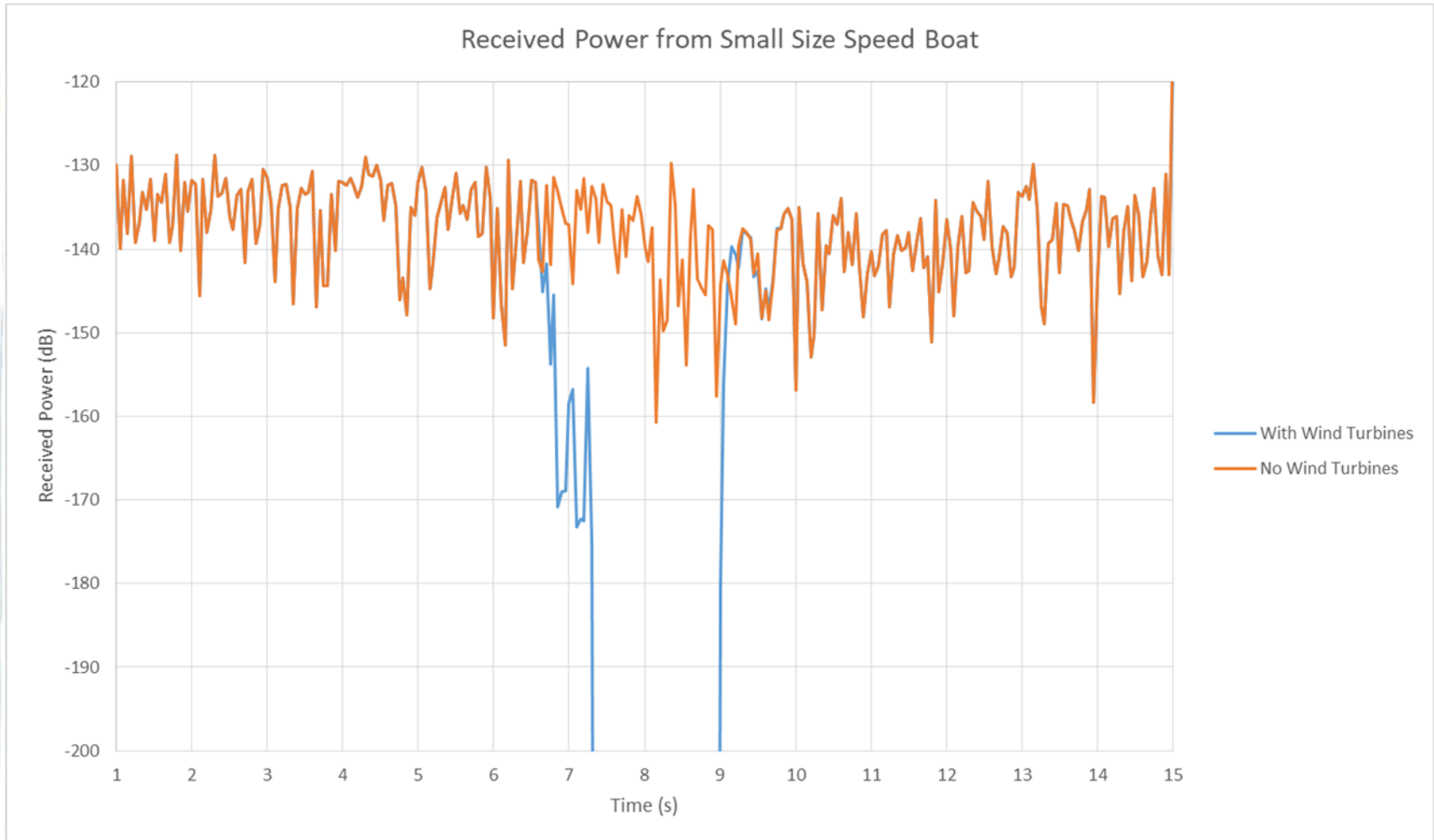
Radar frequency = 9.75 GHz

Target speed = 15 m/s

Terrain & Sea surface are ignored

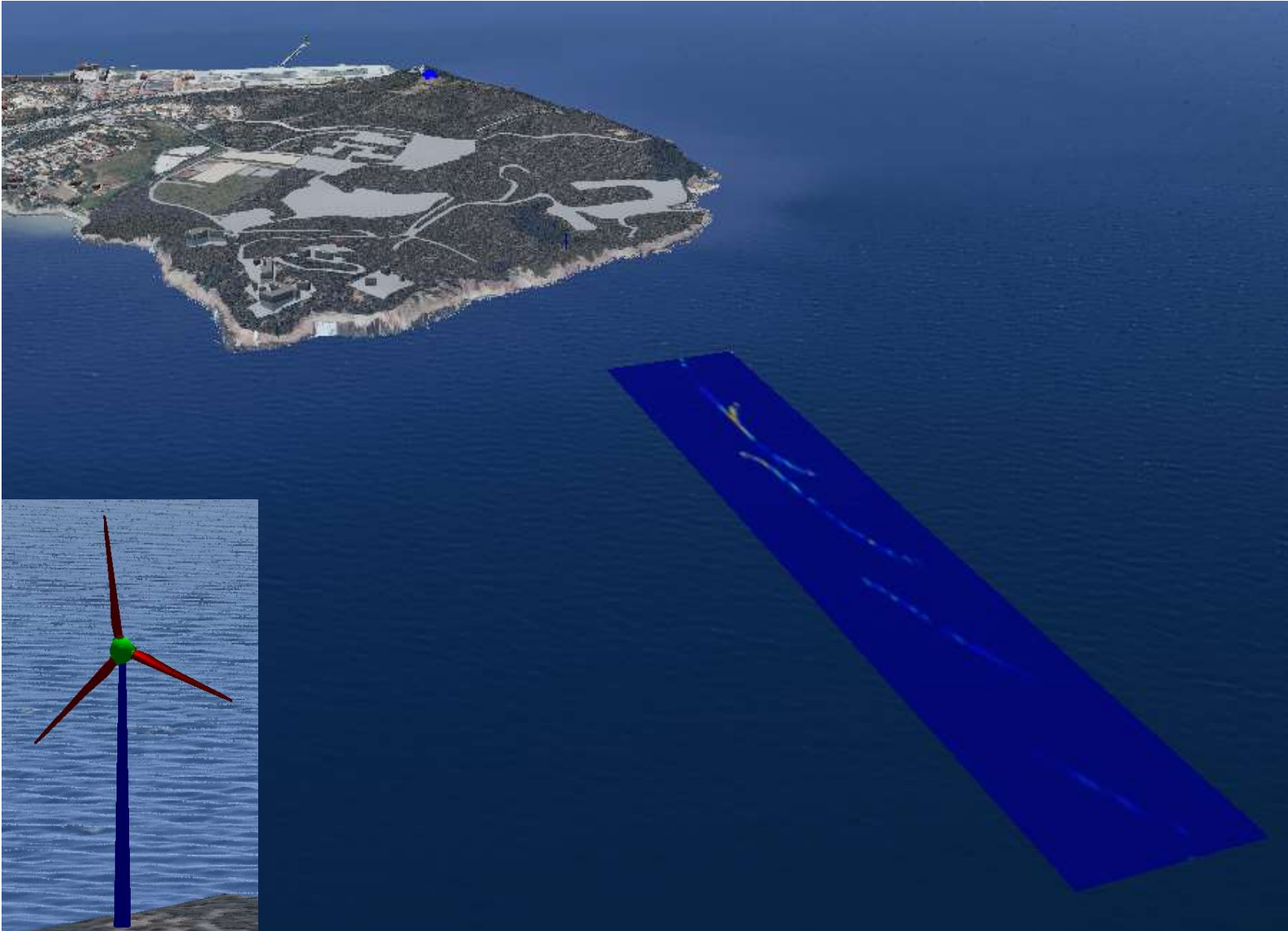
Impact of Wind Turbine on Signal Backscattered by Target

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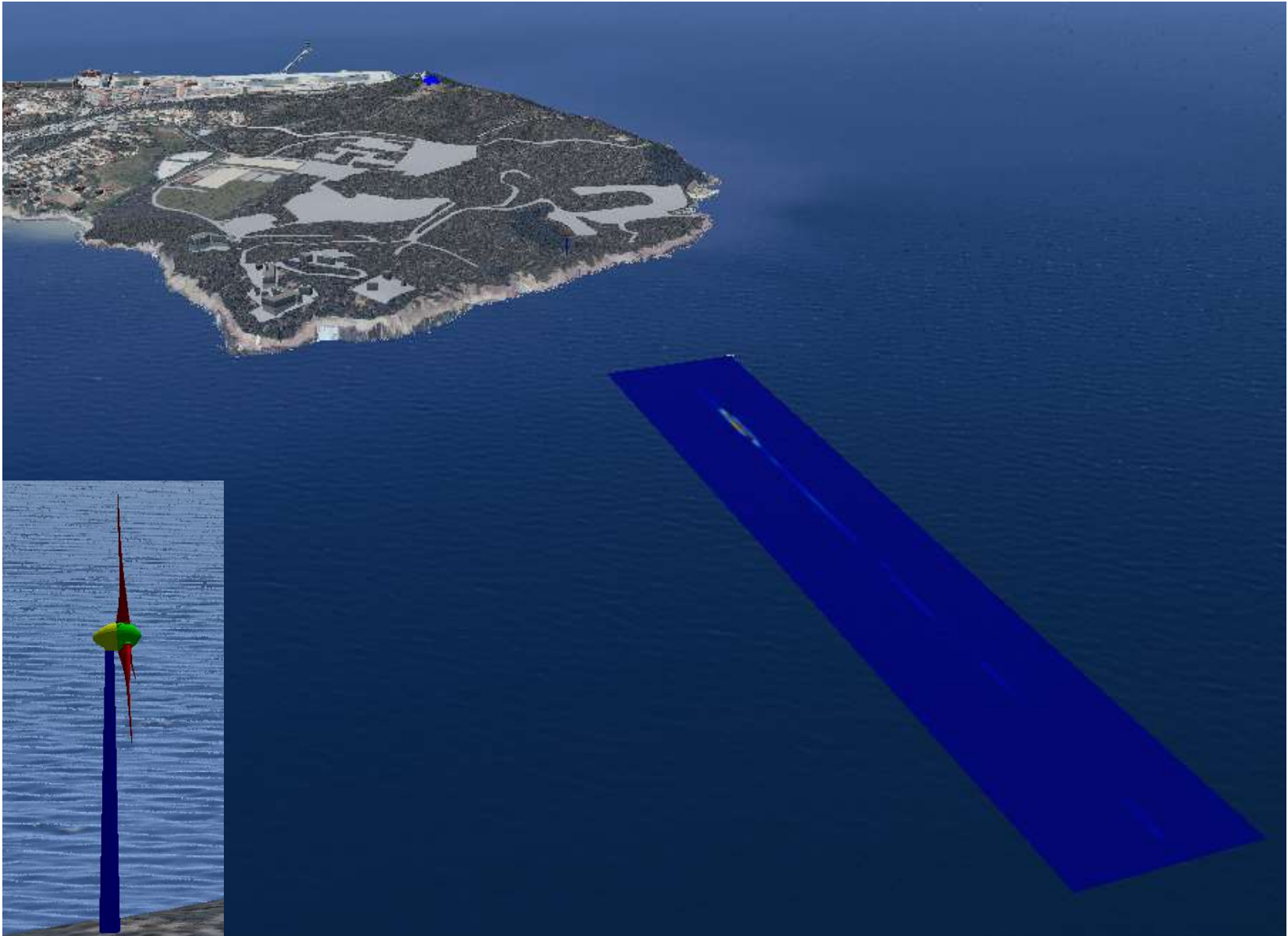
Masking by Wind Turbine

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Masking by Wind Turbine

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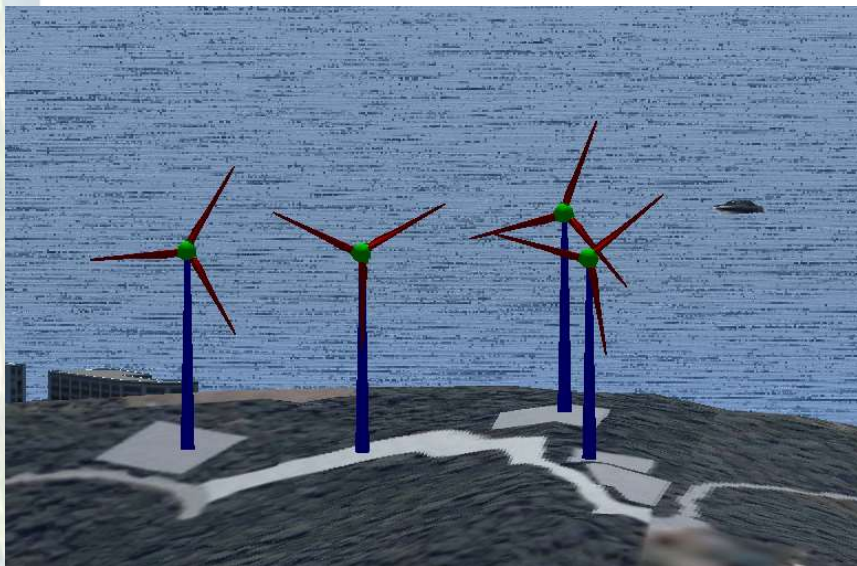


Scenario with a Wind Farm further from the radar

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Wind Farm at Sea Shore



Wind Farm & Target in background

Distance between radar and WF = 7 km

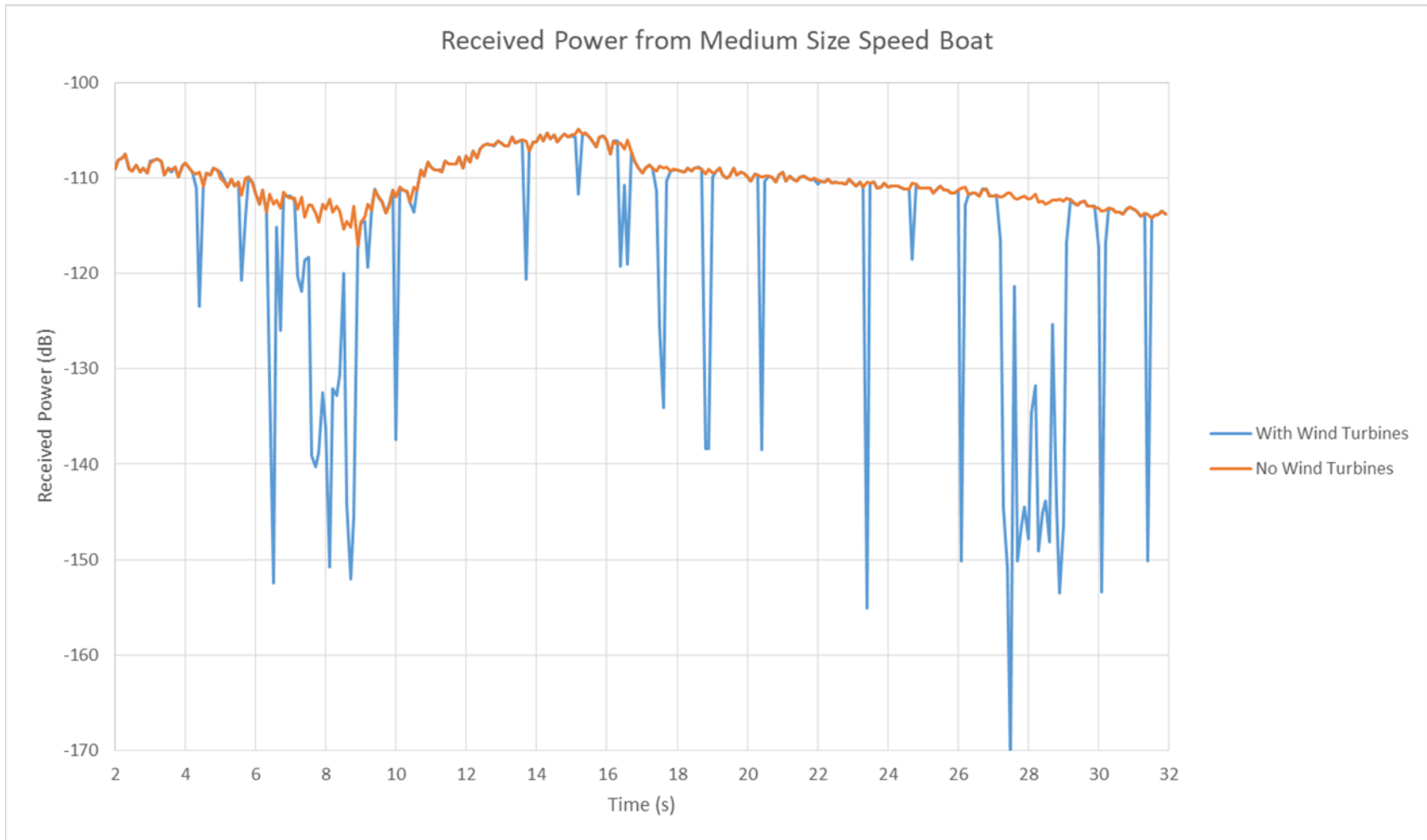
Radar frequency = 9.75 GHz

Target speed = 15 m/s

Terrain & Sea surface are ignored

Impact of Wind Farm on Signal Backscattered by Target

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High fidelity Radar Simulation is considered more and more as a complementary/alternative solution to real measurements

But ...

This kind of simulation still needs to be further validated, in different sensor configuration and environments

Some complex situations require further modelling

Vegetation

Atmospheric effects such as phase scintillation

And also ...

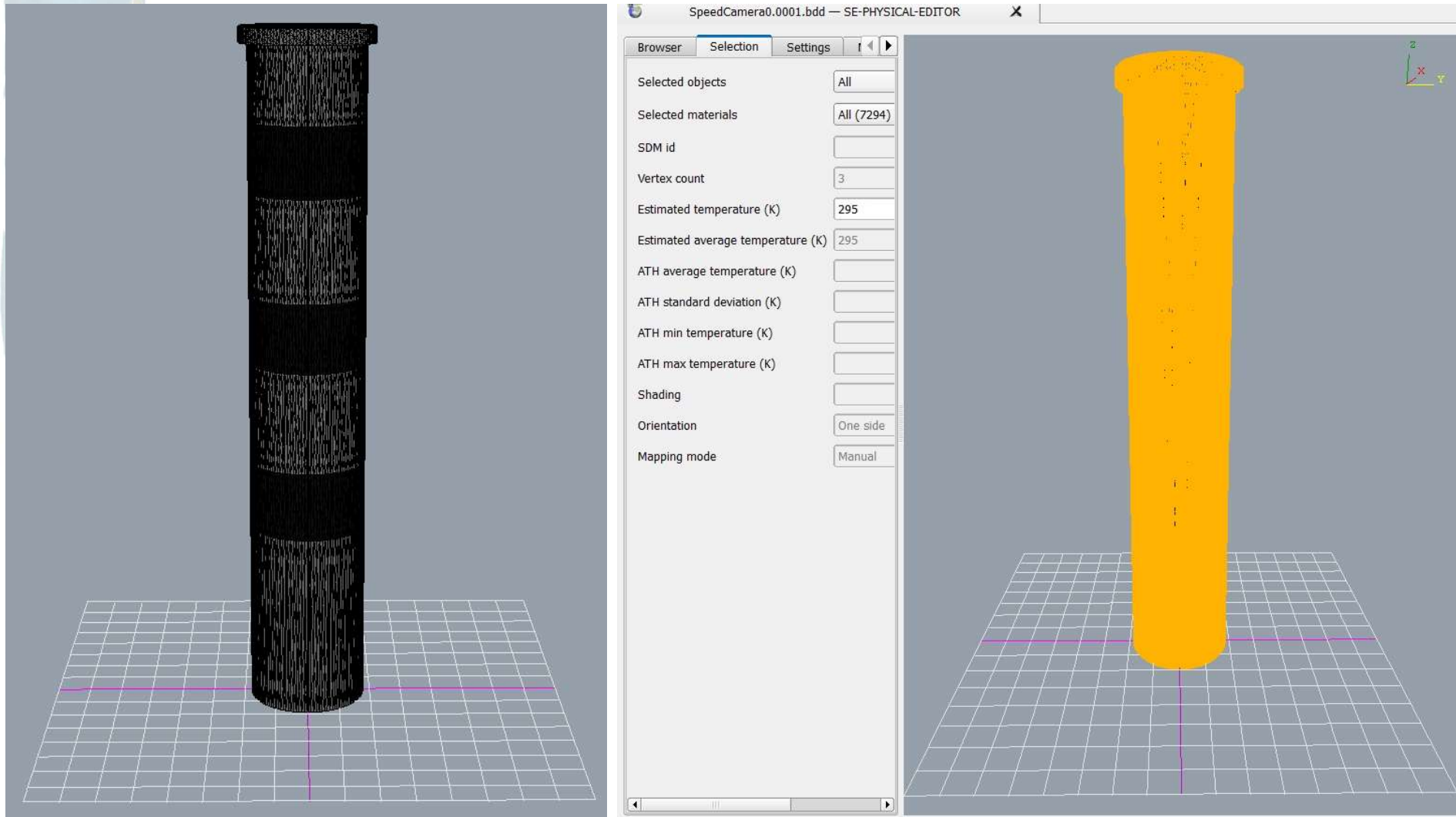
High-fidelity Radar Simulation requires high fidelity input data

High fidelity Synthetic Environment 3D modeling

Physical characterization of materials

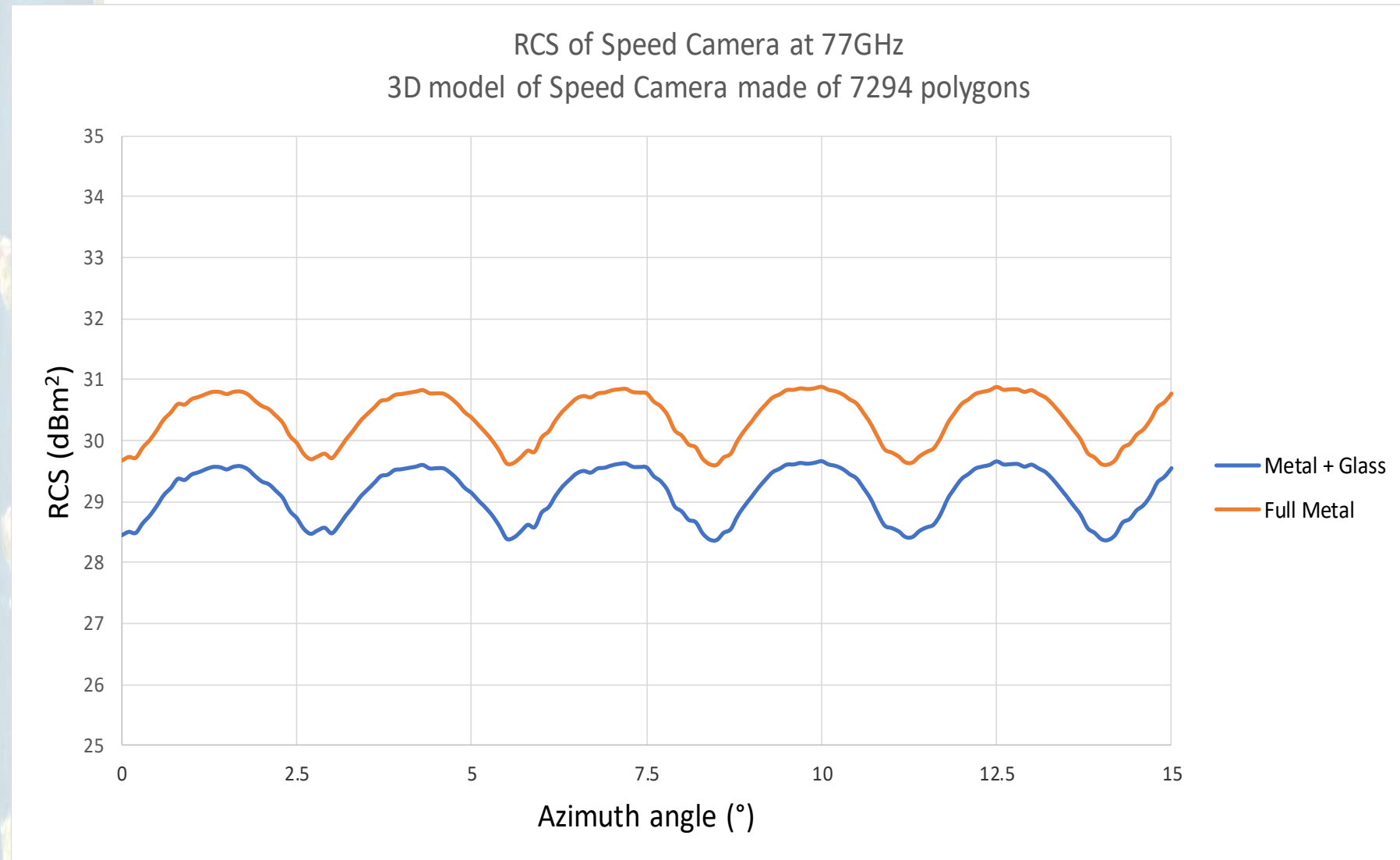
Modeling of the atmosphere

3D modelling of the Speed Camera



The 3D meshing of the object is adapted to the radar Frequency so that the maximum distance between the meshed surface and the real surface is less than 0.1mm

RCS computation of the Speed Camera



Oscillations are due to the 3D meshing, even if it was adapted