Multi-physics Electromagnetic/Fluid-Mechanical Simulator of Radar Wave-Vortex Monitoring

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Summary of the presentation

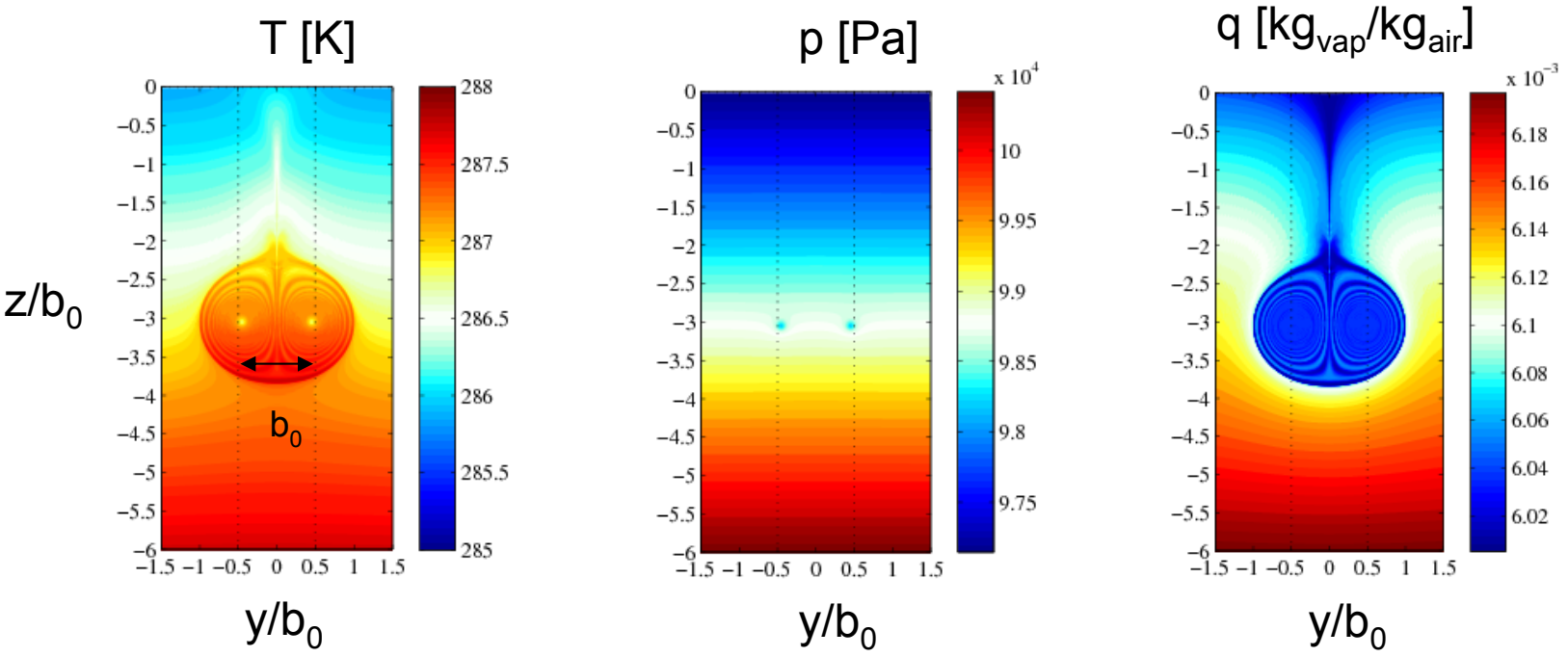
- Objectives of the work
- Preliminary WV simulator
- Equivalent Radar Cross-section
- Wake-Vortex (WV) simulator
  - Existing simulator
  - Inclusion of humidity
- Future work

Objectives

- Modeling of the Radar Cross-Section (RCS) of Wake-Vortices
  - For detection and characterization of Wake-Vortices
  - For simulation of RCS versus various parameters
    - Frequency
    - Angle of incidence
- Present stage = Preliminary study
- Methodology
  - Preliminary simplified simulation of the vortex (pressure, temperature, humidity)
  - Calculation of the refractive index
  - Backscattering of the 3D-refractive index structure
  - Calculation of the RCS

Fluid-Mechanics - Preliminary simulations

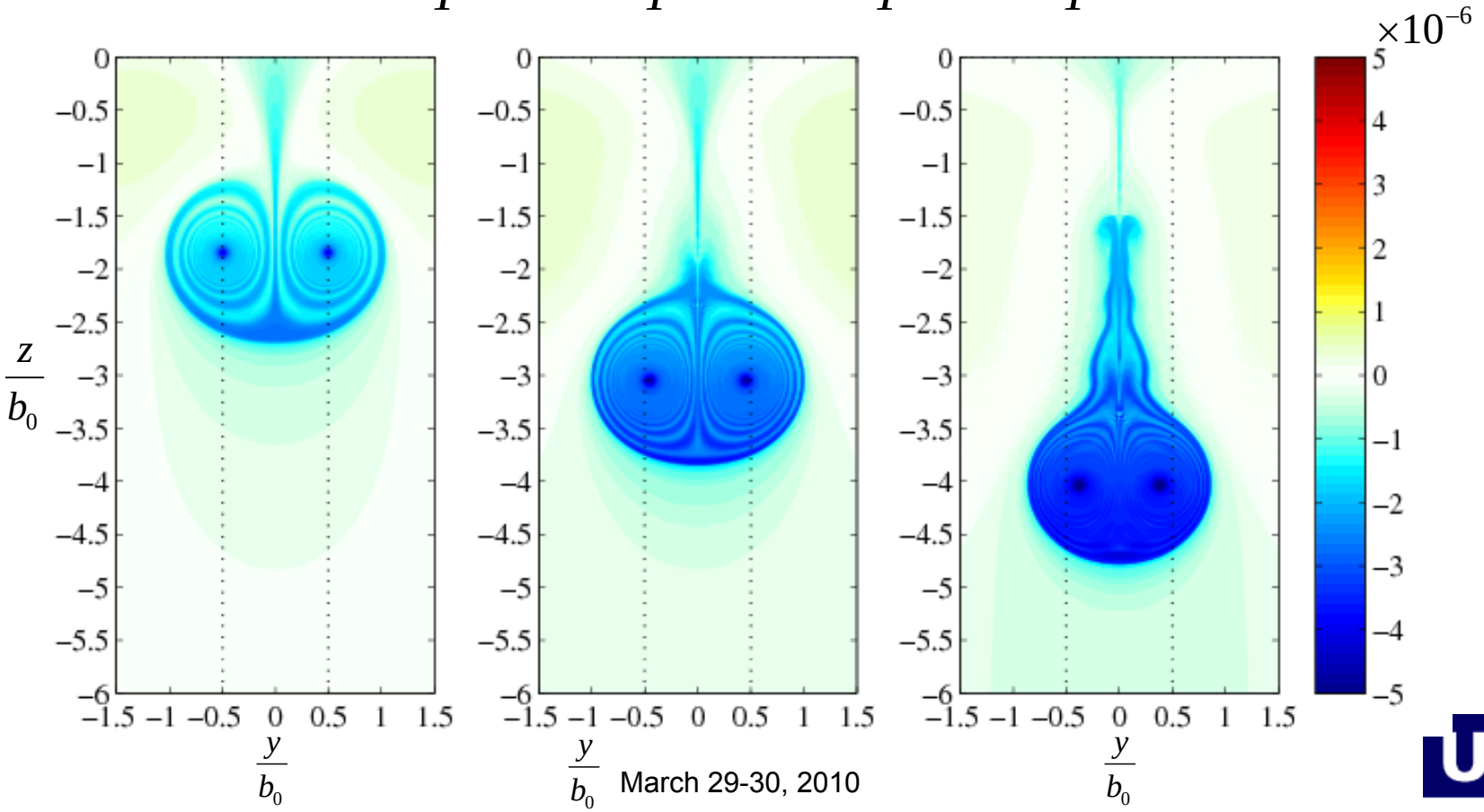
- Numerical simulations of the Navier-Stokes equations, with Boussinesq approximation
- Vertical atmospheric stratification for humidity and temperature (Standard Atmosphere)
- 2D pseudo-spectral code



Dielectric permittivity of air

- Empirical formula of Thayer

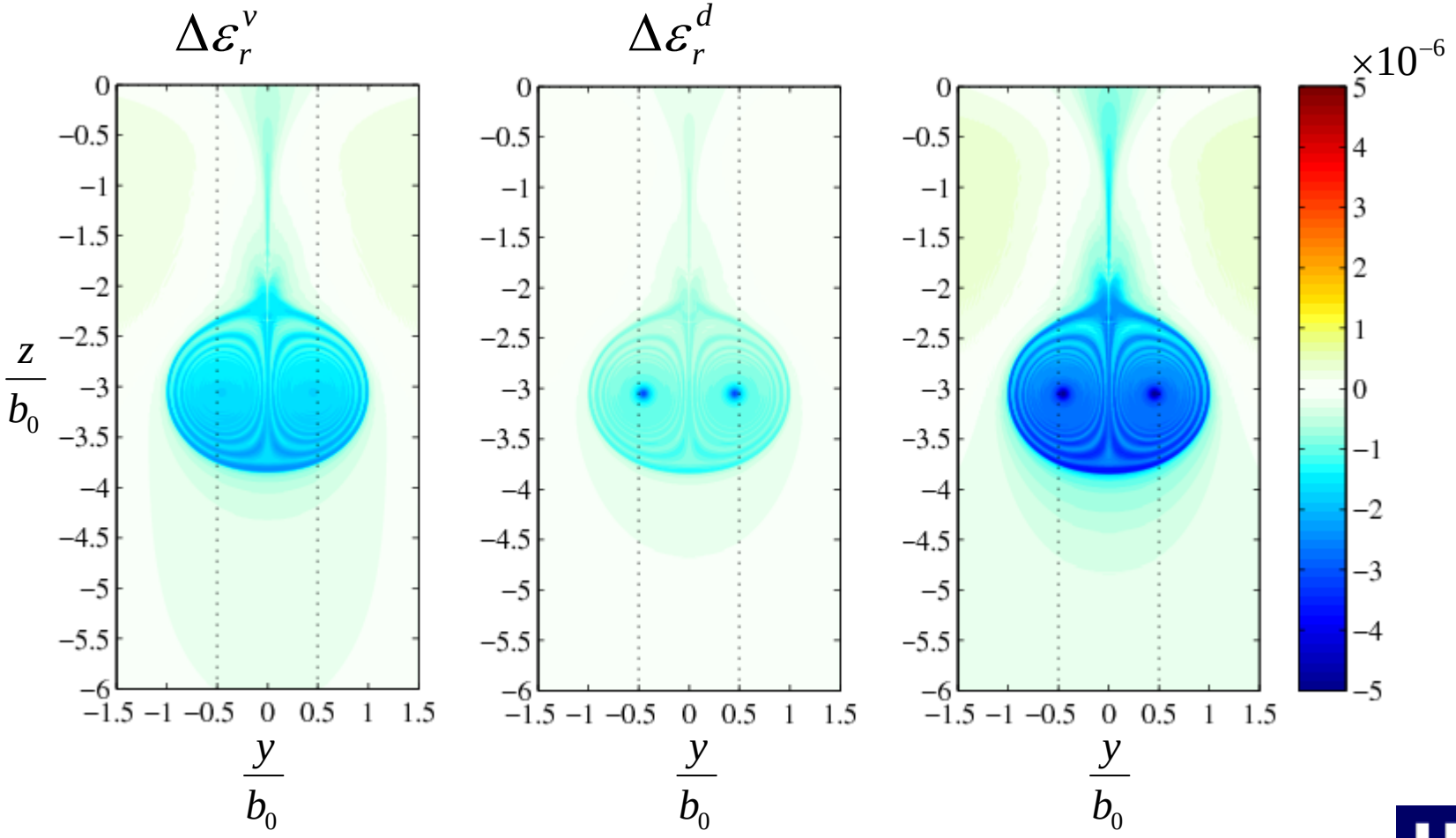
$$(n-1)\times 10^6 = 0.776\frac{p_d}{T} + 1.33\frac{p_{CO_2}}{T} + 0.648\frac{e}{T} + 3776\frac{e}{T^2}$$



Dielectric permittivity of air

- Contribution of the various constituents

Water vapour $\Delta\varepsilon_r^v$ Dry air $\Delta\varepsilon_r^d$ Total

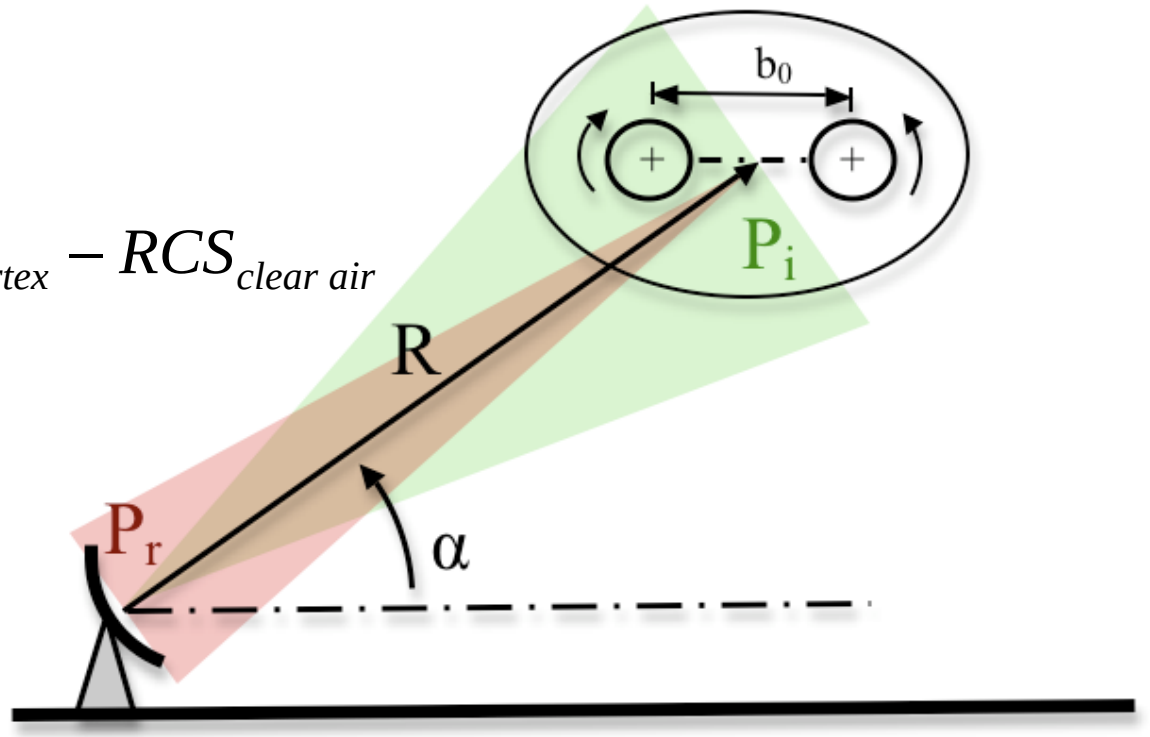


Equivalent Radar Cross-Section

- Geometry of the calculation

$$RCS = 4\pi R^2 \frac{P_r}{P_i}$$

$$\Delta RCS = RCS_{withvortex} - RCS_{clear\ air}$$



Equivalent Radar Cross-Section

- Back-scattered Electric Field

$$\mathbf{E_r}(\mathbf{x_r}) = \nabla \times \nabla \times \int_V (\varepsilon_r(\mathbf{x}) - 1)\mathbf{E}(\mathbf{x}) \frac{e^{jk|\mathbf{x_r}-\mathbf{x}|}}{4\pi|\mathbf{x_r}-\mathbf{x}|} dV$$

Oscillating integral

- Hypotheses
  - Born approximation $\mathbf{E}(\mathbf{x}) \approx \mathbf{E_i}(\mathbf{x})$
  - Far field $\frac{1}{|\mathbf{x_r}-\mathbf{x}|} \approx \frac{1}{R}$

Equivalent Radar Cross-Section

- Two resolution methods of the oscillating integral have been compared
  - Quadrature method of Shariff and Wray
  - Quadrature method of Li
- Comparison has been made on a test case

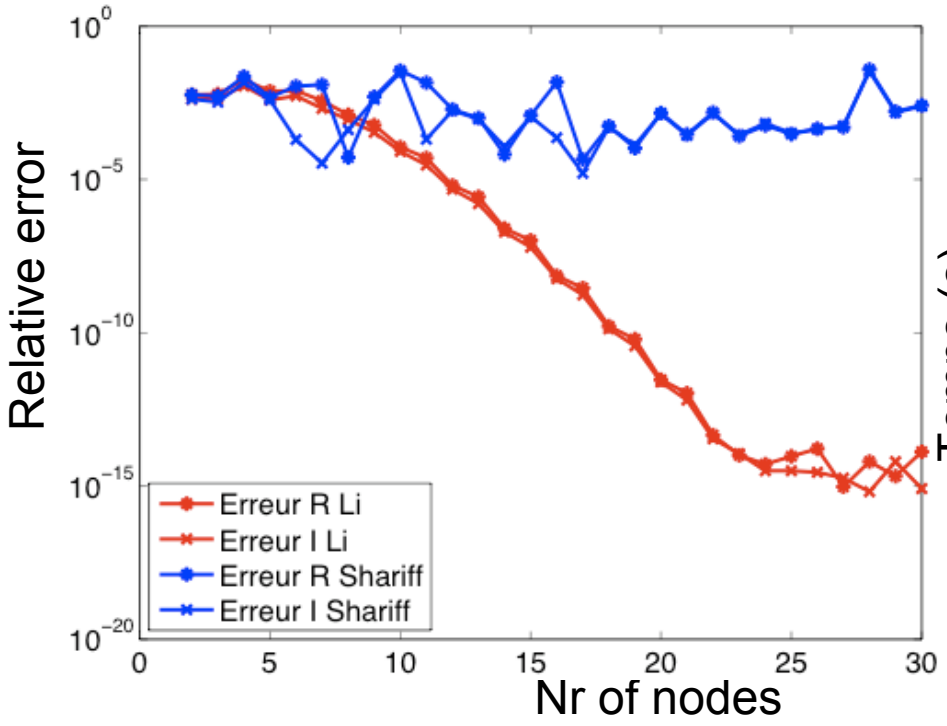
$$\int_0^1 \int_0^1 \int_0^1 \cos(10(x+y+z)) e^{j10^4 (x+y+z)} dxdydz$$

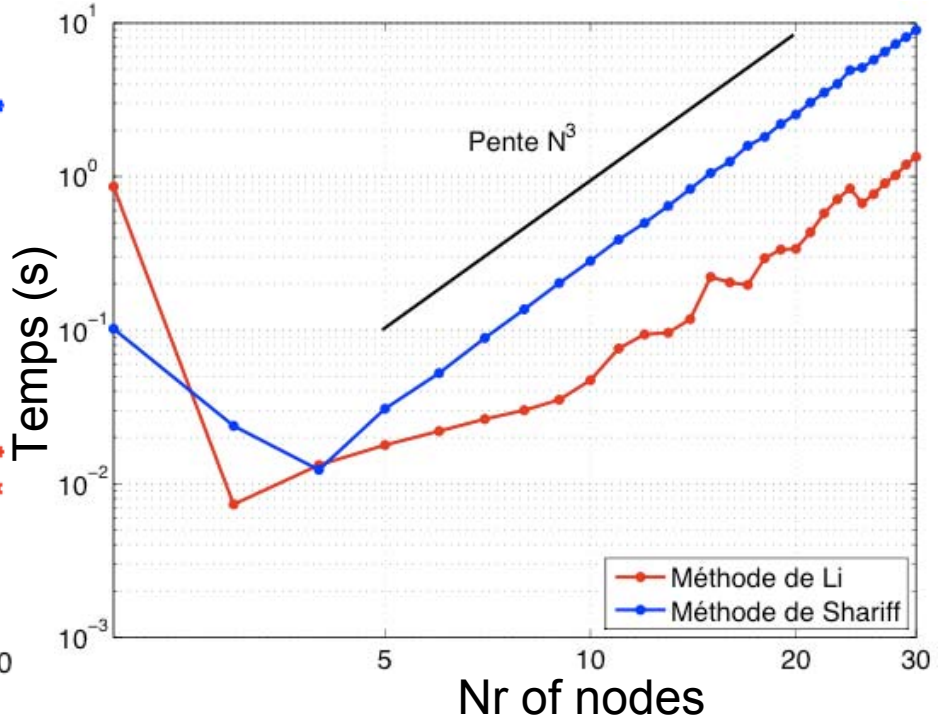
- and on the backscattering of a dielectric sphere

$$\varepsilon_r - 1 = 10^{-6}$$

Equivalent Radar Cross-Section

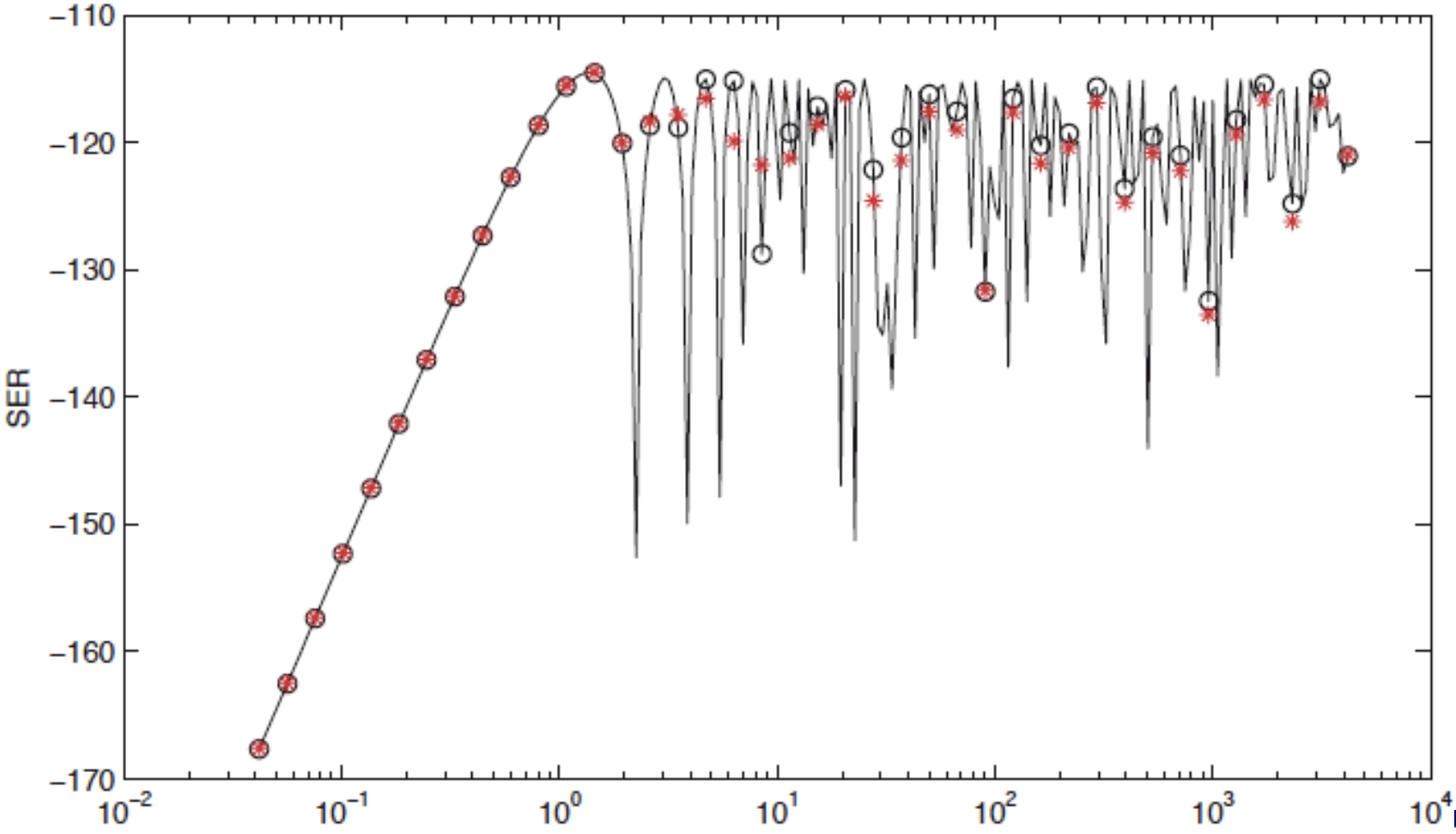
- Comparison between the two integration methods





Equivalent Radar Cross-Section

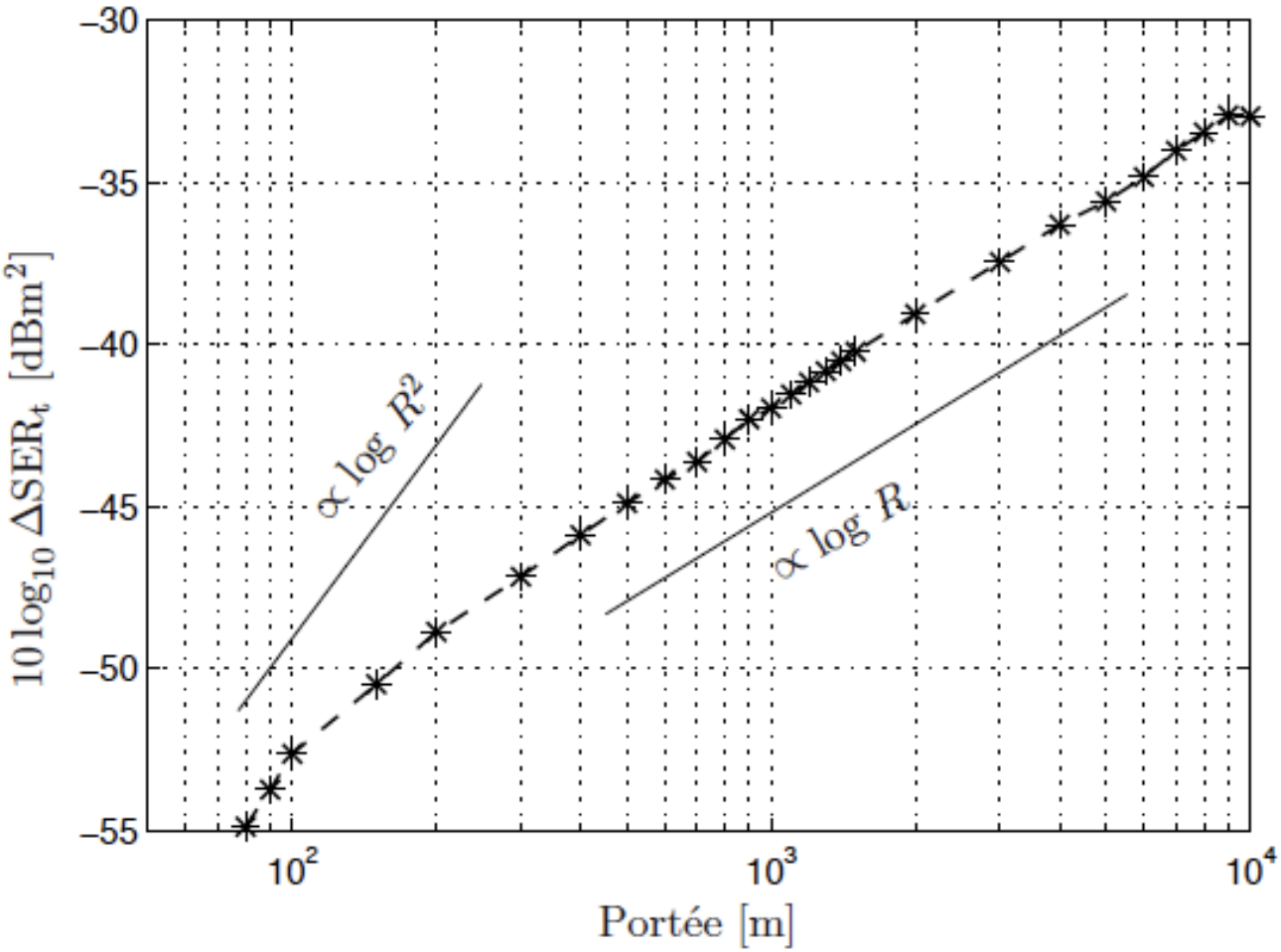
- RCS of a dielectric sphere



Equivalent Radar Cross-Section

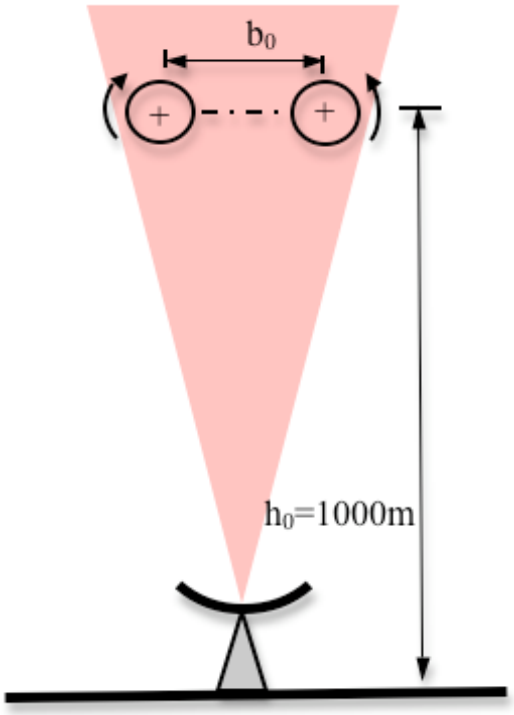
f=10GHz	d/λ=16
R	α=0°

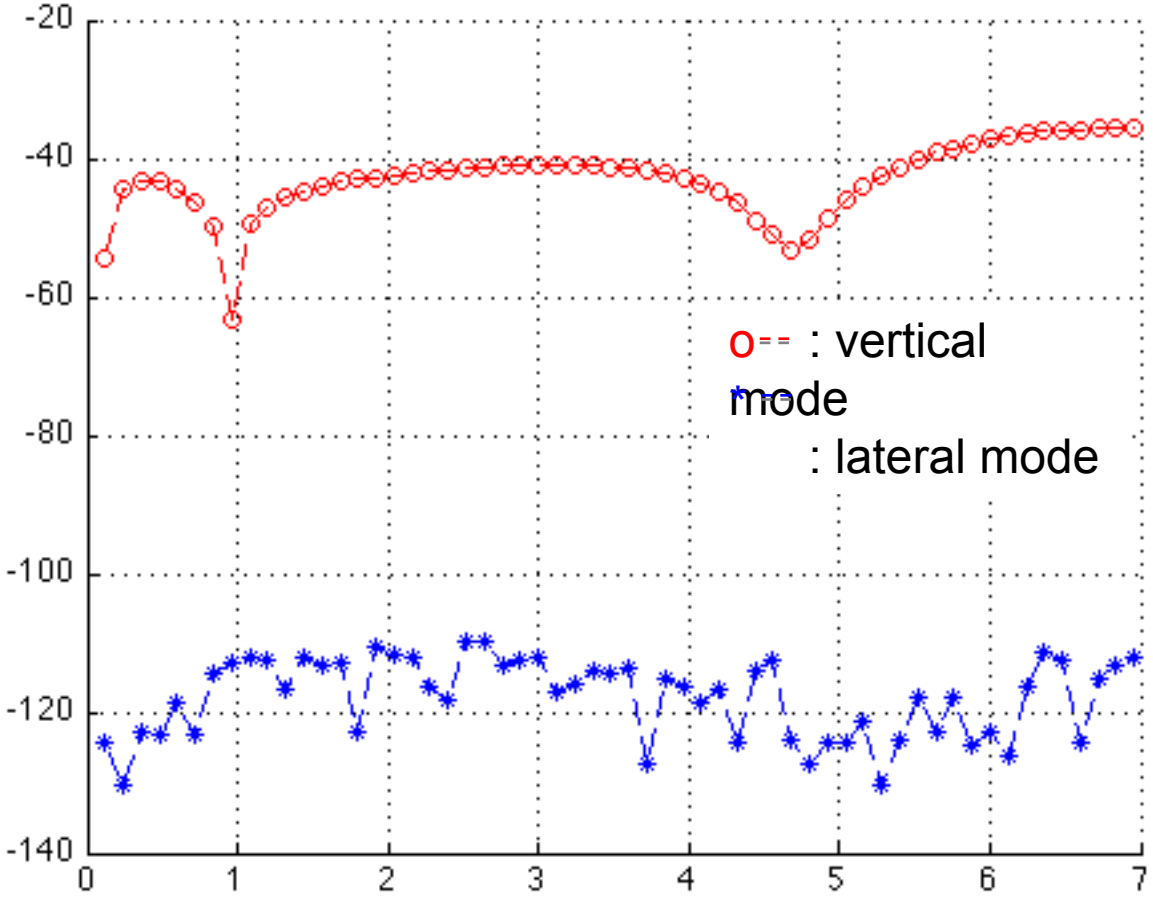
- Influence of the distance



Equivalent Radar Cross-Section

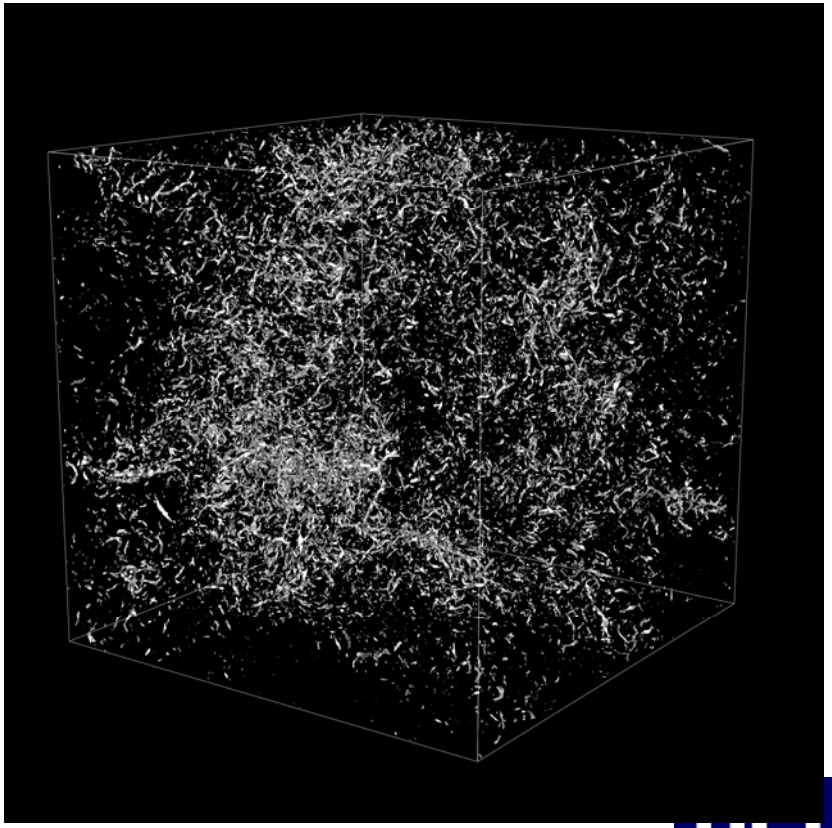
- As a preliminary result, vertical models seems more favorable





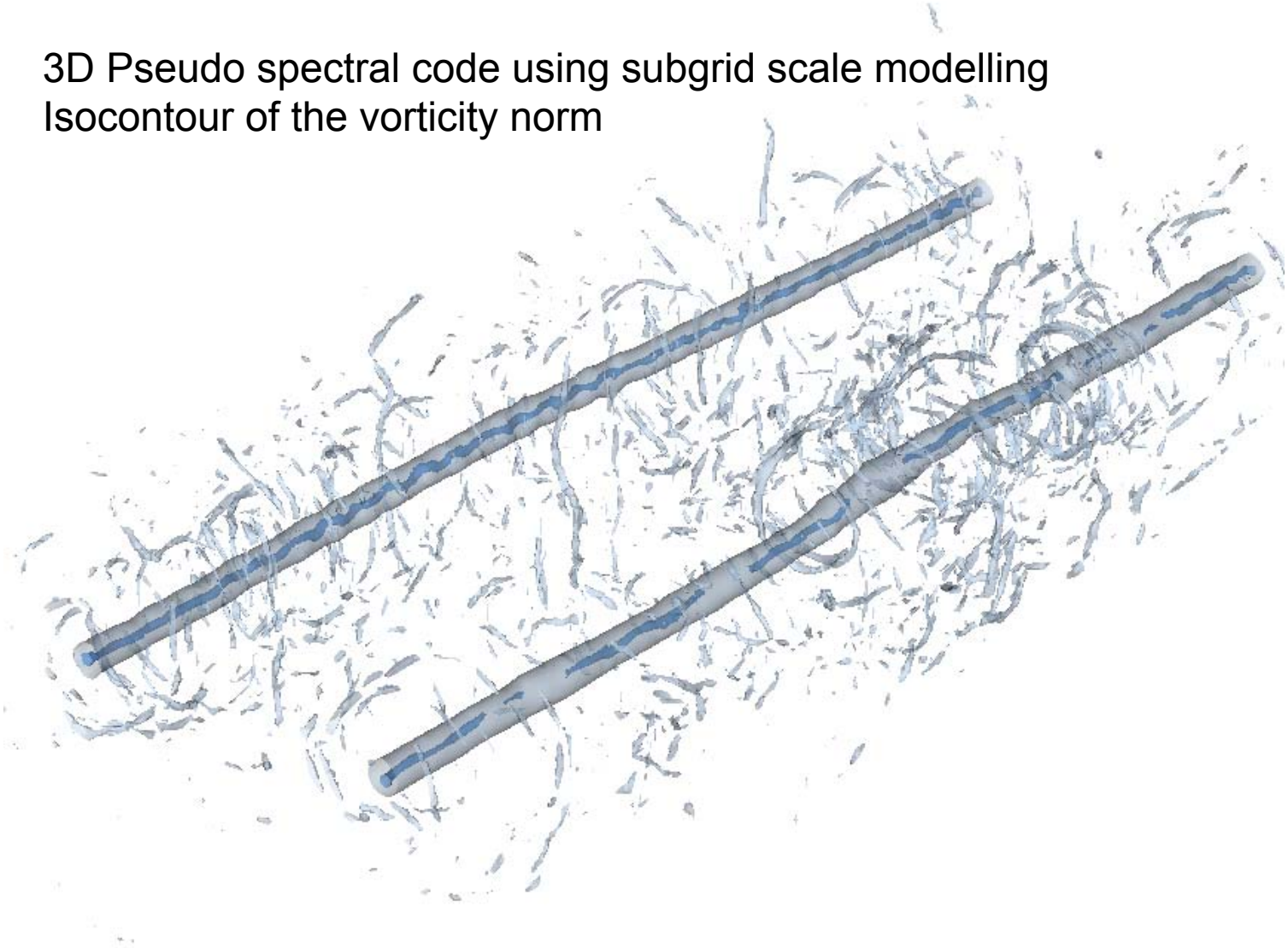
Wake-vortex simulator

- Existing software
  - Output of the code = velocity and temperature
  - Humidity has to be added in the near future
- Starting point: turbulence box



Wake-vortex simulator

3D Pseudo spectral code using subgrid scale modelling
Isocontour of the vorticity norm



Future work

- Participation in the SESAR project
- Evaluation of the Radar Cross-Section integral
  - Direct calculation of the electric field, power and RCS
  - Evaluation of the possibility to calculate in the spectral domain (use of the Kolmogorov spectrum for dm and cm range)
- Evaluation of the effect of the rain on the sensitivity of the detection
  - Insertion of a rain slab between radar and vortex
  - Insertion of rain droplets in the vortex

- Thank you for your attention