A fast approach to compute atmospheric radiative transfer in non scattering medium

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Context

- Studying impact of the climate on EDF facilities and reciprocally : problem of cloudy atmosphere for photovoltaic energy production
- Having a local-scale forecast model able to simulate fog formation and evolution
- Taking account spatial heterogeneities with a 3-D Radiative Transfer model


Basic Concepts

- Plane-parallel atmosphere : stacked homogeneous layers
- $\Rightarrow$ Absorption coefficients are horizontally constant
- Radiative properties are parametrized by emissivity functions fitted on charts

$$\epsilon : \left(z', z\right) \mapsto \frac{1}{\sigma T^4} \int_0^{+\infty} \left[1 - \tilde{\mathcal{T}}\left(z, z'\right)\right] \pi I_\lambda^o\left(z'\right) d\lambda$$

Objectives

- Using a 3-D resolution method, fast as possible and accurate enough
- Coupling emissivity functions with Discrete Ordinates Method
- Comparisons of heating rates and fluxes computed by the existing and validated 1-D model in atmospheric module of ***Code_Saturne***®
- Comparisons with a radiative transfer model which uses multi-spectral resolution (Correlated-K Distribution)

Theoretical approach - Plane-Parallel Amtmosphere

Radiative Transfer Equation on fluxes

$$\frac{\partial F^\uparrow}{\partial z}(z) = -\frac{3}{5}k(z)\left[F^\uparrow(z) - \sigma T^4(z)\right]$$
$$\frac{\partial F^\downarrow}{\partial z}(z) = \frac{3}{5}k(z)\left[F^\downarrow(z) - \sigma T^4(z)\right]$$

$$F^\uparrow(z) = \sigma T_g^4\left(1 - \epsilon(z,0)\right) + \epsilon(z,0)\,\sigma T_A^4$$
$$F^\downarrow(z) = \epsilon\left(z, z_\infty\right)\sigma T_A^4$$

Solution for the Cooling to Space approximation

$\Rightarrow$

Radiative Transfer Equation on radiance

$$cos\theta \frac{\partial I}{\partial z}(z, cos\theta) = -k(z)\left[I(z, cos\theta) + I^o(z)\right]$$

where k(z) is equal $k^\uparrow(z)$ if $\cos\theta > 0$ and $k^\downarrow(z)$ if $\cos\theta > 0$

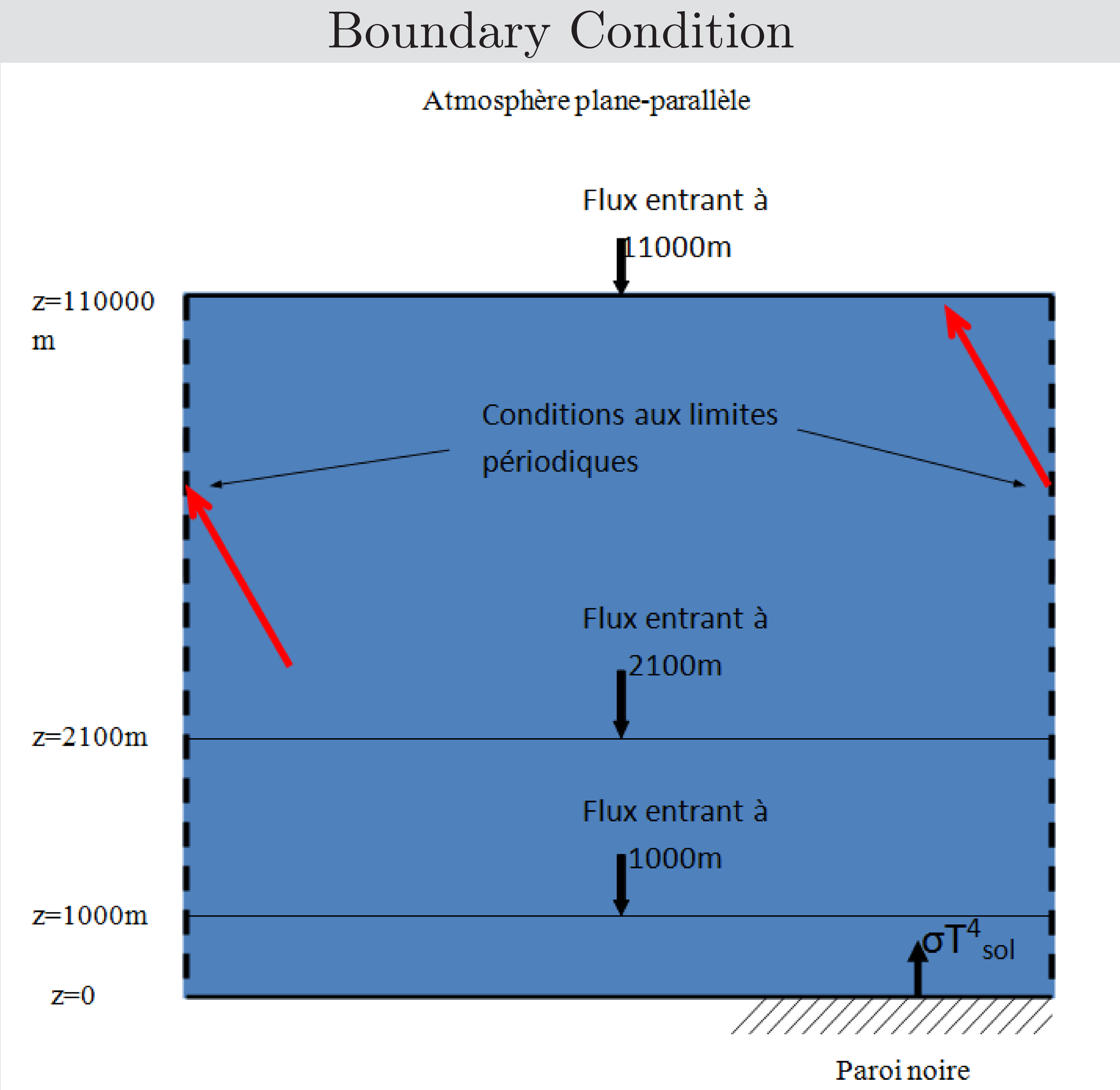
$$k^\uparrow(z) = \frac{3}{5}\frac{\partial \epsilon^\uparrow}{\partial z}(0, z)\frac{1}{\left[1 - \epsilon^\uparrow(0, z)\right]}$$

$$k^\downarrow(z) = -\frac{3}{5}\frac{\partial \epsilon^\downarrow}{\partial z}(z, z_\infty)\frac{1}{\left[1 - \epsilon^\downarrow(z, z_\infty)\right]}$$

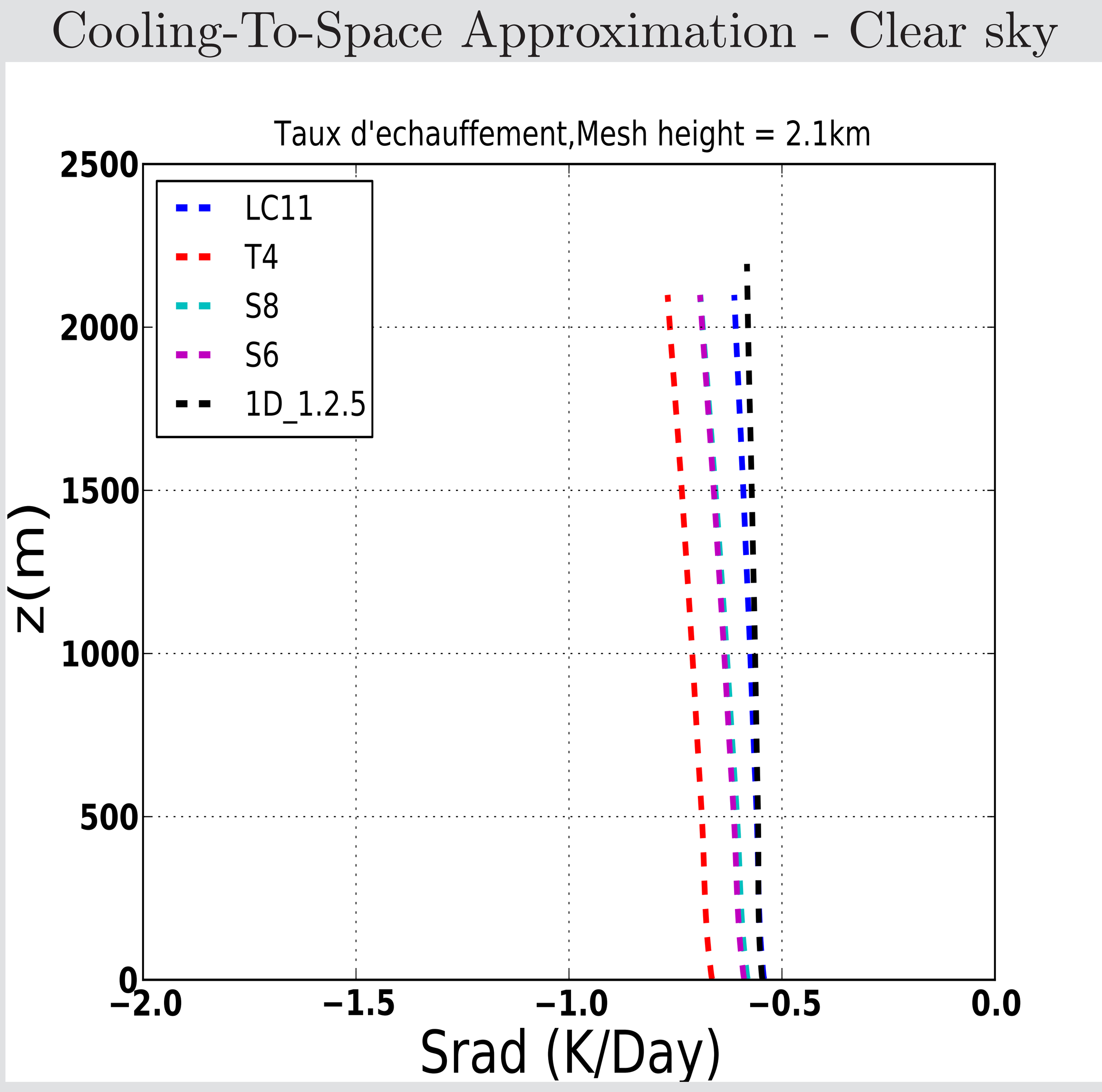
- Radiative properties averaged over the whole spectrum to save time computing
- Different mean absorption coefficient for upwards and downwards directions has no physical sense
- Exact mathematical approach for an isothermal atmosphere (Cooling-To-Space)

Heating/Cooling rates comparisons - Clear sky conditions - Validation

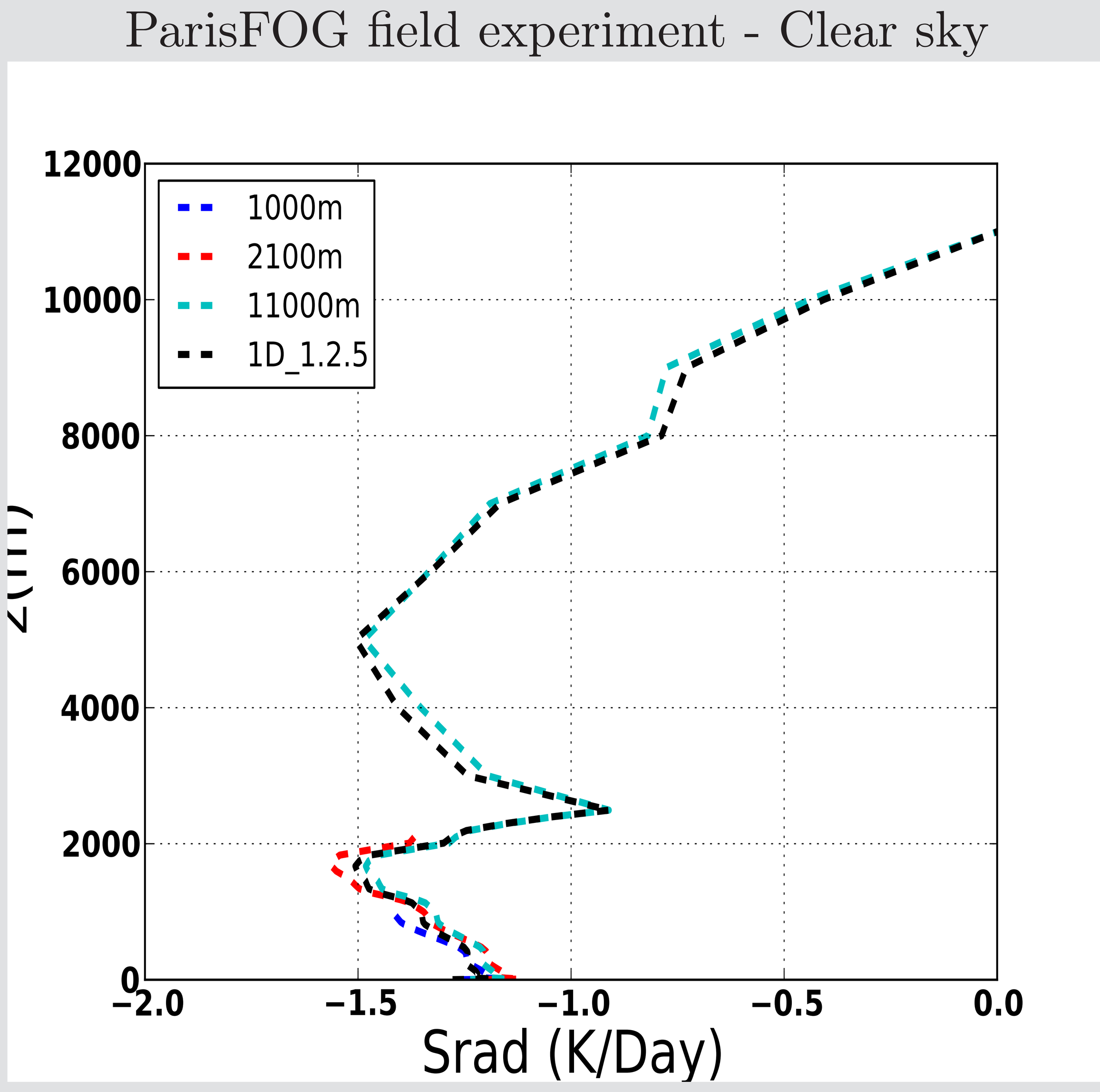
Boundary Condition



Cooling-To-Space Approximation - Clear sky

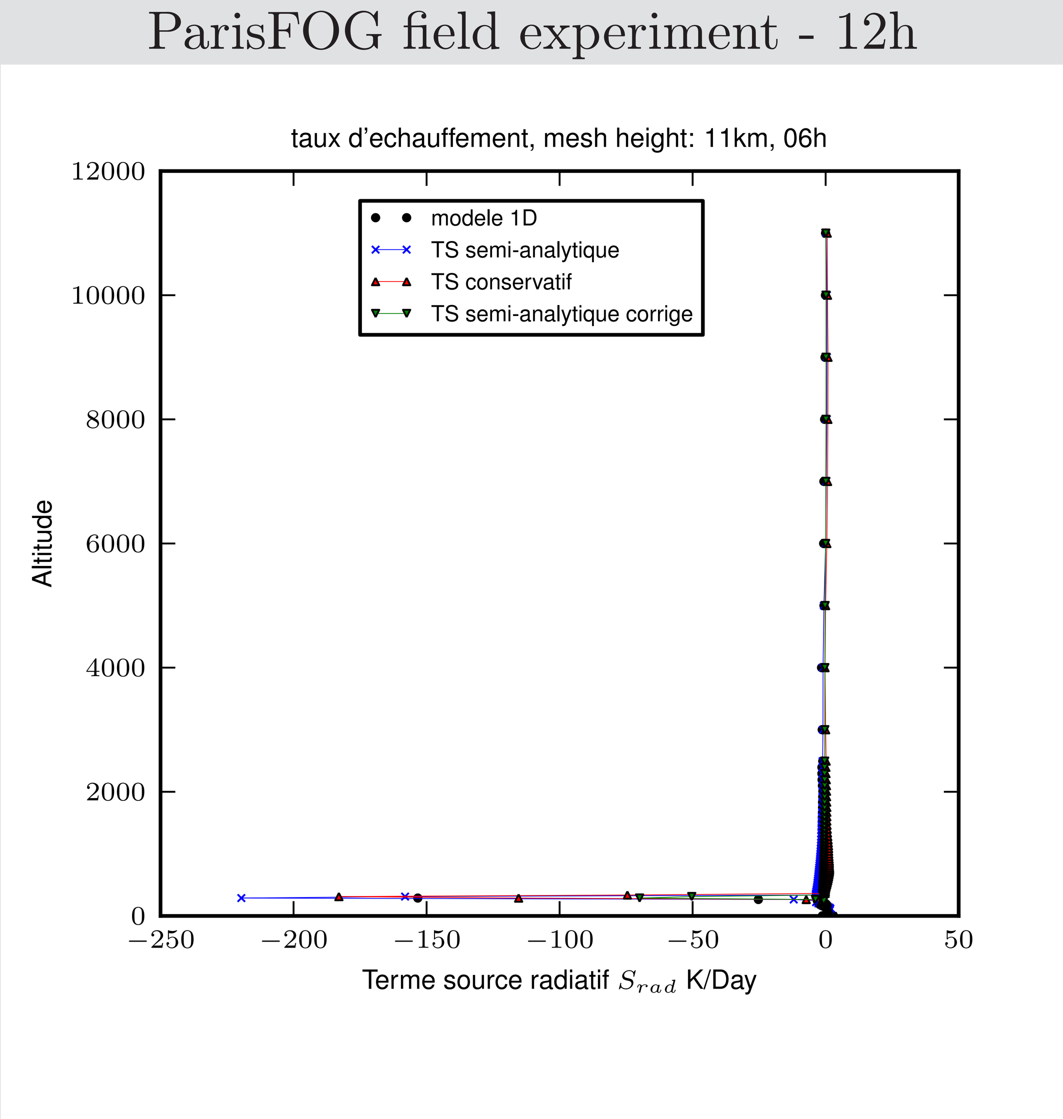


ParisFOG field experiment - Clear sky



Cloudy Atmosphere

ParisFOG field experiment - 12h



Conclusion/Further work

- New approach fast and accurate enough validated on semi-analytical solutions
- Infrared heating/cooling rates in clear sky or cloudy condition : strong cooling above the fog layer, heating below it
- Weak/Strong coupling of our approach with Fluid Dynamics

Definitions

- I : radiance
- $F^{\uparrow\downarrow}$: upward and downward fluxes
- I^0 Planck function
- Srad : Divergence of the radiative flux called heating rate
- k gray absorption coefficient
- T_A temperature of the atmosphere
- T_g temperature of the ground
- $\tilde{\mathcal{T}}$ transmittance function
- $\epsilon : \left(z', z\right)$: emissivity between z' and z

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