# Combining the independent pixel and point-spread function approaches to simulate the actinic radiation field in moderately inhomogeneous 3D cloudy media


**Anke Kniffka[1], Thomas Trautmann[2]**

(1) Institute for Meteorology, University of Leipzig, 04103 Leipzig, Germany
(2) Remote Sensing Technology Institute, DLR Oberpfaffenhofen, 82234 Wessling, Germany


## Introduction

A fast method is presented for gaining 3D actinic flux density fields, $F_{act}$, in clouds employing the Independent Pixel Approximation (IPA) with a parameterized horizontal photon transport to imitate radiative smoothing effects. For 3D clouds the IPA is an efficient method to simulate radiative transfer, but it suffers from the neglect of horizontal photon fluxes leading to significant errors (up to locally 30% in the present study). Consequently, the resulting actinic flux density fields exhibit an unrealistically rough and rugged structure. In this study, the radiative smoothing is approximated by applying a physically based smoothing algorithm to the calculated IPA actinic flux field.

## Gaussian smoothing and PSF

Point Spread Function (PSF) for a scattering & absorbing medium: The spreading of a beam normal to its travelling direction in the medium follows a Gaussian law (Premoze et al., 2004 and Tessendorf, 1987) with width of the distribution:

$$b^2(S) = \frac{2(1-g)\beta_{sca} S^3}{16(1+S^2/(12l^2))}$$

$S$ = path through the medium, $g$ = asymmetry parameter, $\beta_{sca}$ = scattering coefficient, $l$ = diffusive path length with $l^2=1/(\beta_{abs}\cdot\beta_{sca}\cdot 2(1-g))$, $\beta_{abs}$ = absorption coefficient

Gaussian smoothing of a single layer of the $F_{act}$ field:

$$F_{act}(x,y) = \frac{1}{a}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} F_{act,IPA}(x',y') \cdot e^{-\frac{(x-x')^2+(y-y')^2}{b^2}} dx'\,dy'$$

Medium contains standardized profiles of air molecules, aerosol particles, molecular O3 and NO2

## Method and radiative transfer model

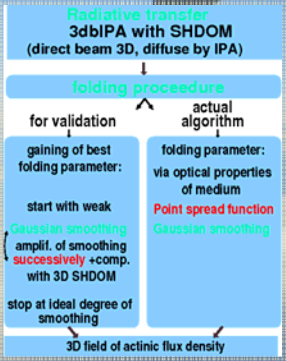


**Fig. 1:** Flow chart of $F_{act}$ simulation.

Radiative transfer calculations: SHDOM (Spherical Harmonics Discrete Ordinate Method), 3D IPA using direct beam (3dbIPA by Evans and Gabriel, 1996)

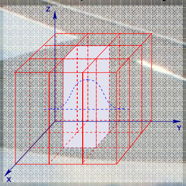

**Fig. 2:** IPA + smoothing

Determination of the convolution parameter: i) empirically (control method) or ii) with PSF (see Fig. 1).

Cloud masks can be applied, i.e. the convolution is performed in cloudy regions only.

## LES cloud field – increasing optical thickness

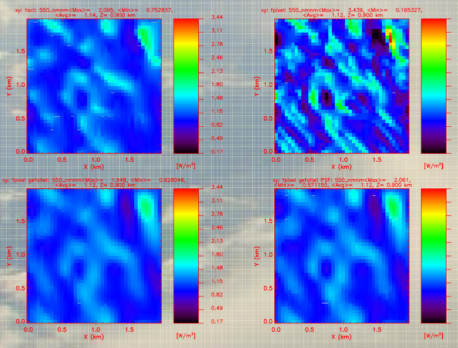

**Fig. 3:** Horizontal cut of $F_{act}$ fields at $\tau$ = 10 and $\lambda$ = 550 nm, upper left $F_{act,3D}$, upper right $F_{act,\,IPA}$, lower left $F_{act,\,IPAsmooth}$, lower right $F_{act,IPAPSF}$.

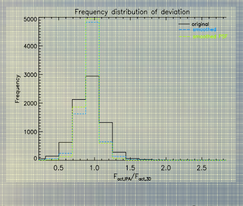


**Fig. 4:** Frequency distribution of $F_{act,IPA}/F_{act,3D}$ control method vs. PSF (all layers).

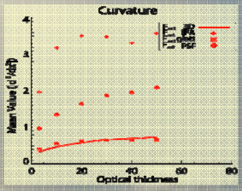


**Fig. 5:** Roughness of $F_{act}$ characterised by 2nd order finite differences vs. $\tau$.

3D inhomogeneous cloud field (thickness 250 m) for for SZA = 66°. Convoluted fields resemble results for 3D simulations much more than 3dbIPA without smoothing, see also ratio $F_{act,IPA}/F_{act,3D}$ in Fig. 4.

Varying $\tau$ of cloud field in Fig. 5: Convolution reduces roughness to resemble 3D result.

## Stratiform cloud: wavelength dependence

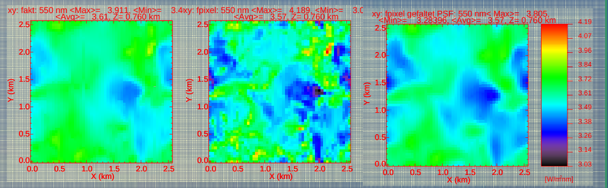

**Fig. 6:** Horizontal cut of $F_{act}$ fields: left $F_{act,3D}$, middle $F_{act,\,IPA}$, right $F_{act,IPAPSF}$, $\lambda$ = 550 nm.

This stratus cloud field was (max. opt. depth ~ 28, max. vertical extent ~ 300 m) created with IAAFT cloud generator algorithm (Venema et al., 2006). The simulation was carried out at 0° SZA.

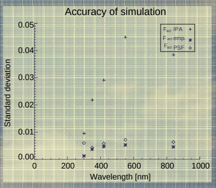


**Fig. 7:** Wavelength dependence of the lateral variability of the $F_{act}$ field: IPA exhibits variability increasing with $\lambda$. Convolution mimics 3D results very well and reduces IPA's $\lambda$ dependence to ~1/10 (not valid for all cloud cases!).

## 2D: Increasing cloud gaps

2D cloud fields via IAAFT method, LWC content is dervied from certain PDF with standard deviation $\sigma$, which is increased from 5 to 27 % to achieve gradually more cloud-free pixels, while overall LWC remains fixed.

SZA = 66°, $\lambda$ = 400 nm, urban aerosol exponentially decaying with altitude.

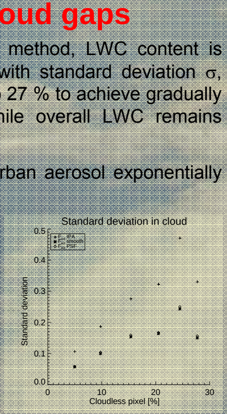


**Fig. 9:** Effectivity of smoothing: standard deviation of $F_{act,IPA}/F_{act,3D}$ of all pixels in cloud region is connected to number of deviating or bad simulated pixels.

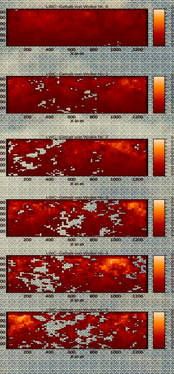

**Fig. 8:** 2D fields of LWC, white pixels are cloud free.

## Discussion

- Horizontal photon transport can be mimicked by combining IPA results with PSF-smoothing kernel.
- Depending on the variability of the cloud structure the convoluted fields show a good resemblance with the exact 3D radiation fields.
- The physically unrealistic roughness of IPA $F_{act}$ fields is reduced; for increasing cloud gaps IPA results get even worse.
- Smoothing helps to improve the wavelength dependency of simulated $F_{act}$ fields.
- Strong reduction of CPU time by the new algorithm (≈ 6 % of a 3D simulation)
- The treatment of "true" 3D transport effects (cf. photon channeling) needs additional considerations.


**References**

Gabriel, P. M., K. F. Evans: Simple radiative transfer methods for calculation domain averaged solar fluxes in inhomogeneous clouds, J. Atmos. Sci., 53,858-877, 1996.

Premoze, S., M. Ashikhmin, R. Ramamoorthi, S. Nayar: Practical rendering of multiple scattering effects in participating media, Eurographics Symposium on Rendering, The Eurographics Association, 2004.

Tessendorf, J.: Radiative transfer as a sum over paths. Phys. Rev. A, 35, 872-878, 1987.

Venema, V., Meyer, S., Gimeno Garcia, S., A. Kniffka, C. Simmer, S. Crewell, U. Löhnert, T. Trautmann, A. Macke: Surrogate cloud fields generated with the Iterative Amplitude Adapted Fourier Transform algorithm, Tellus 58A, 1, 104-120, 2006.