A Monte Carlo Model model for UV+VIS 3D radiative transfer calculation

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•Motivation:

•retrieval of trace gas profiles

from measurements by means of

Differential Optical Absorption Spectroscopy (DOAS)

using e.g. AMFs, box AMFs and weighting functions

•modelling of directional sensitivities for campaign planning (LOS optimization)

•modelling of photolysis frequencies for chemical model input

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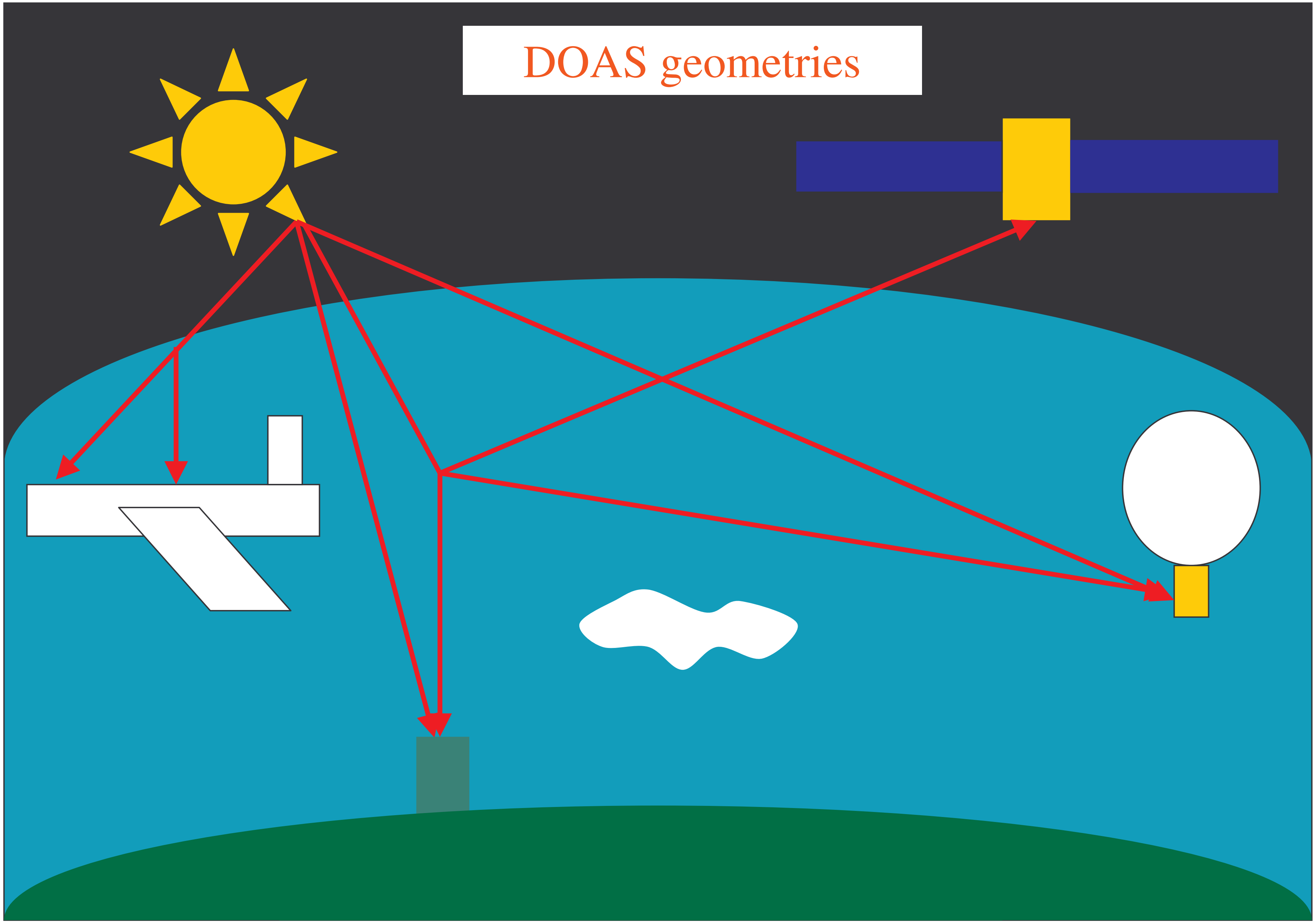

DOAS geometries

Implemented features

- spherical 3D geometry
- arbitrary platform positions and viewing geometries
  including e.g. Multi-axis, nadir, limb
- full multiple scattering (MS) by Rayleigh and Mie
- refraction and albedo
- aerosol loads
- backward and forward Monte Carlo for MS
- forward level-wise mode for single scattering SingS
- Simple cloud module (albedo, transmission, altitude, coverage) for satellite geometry

Geometry

Spherical

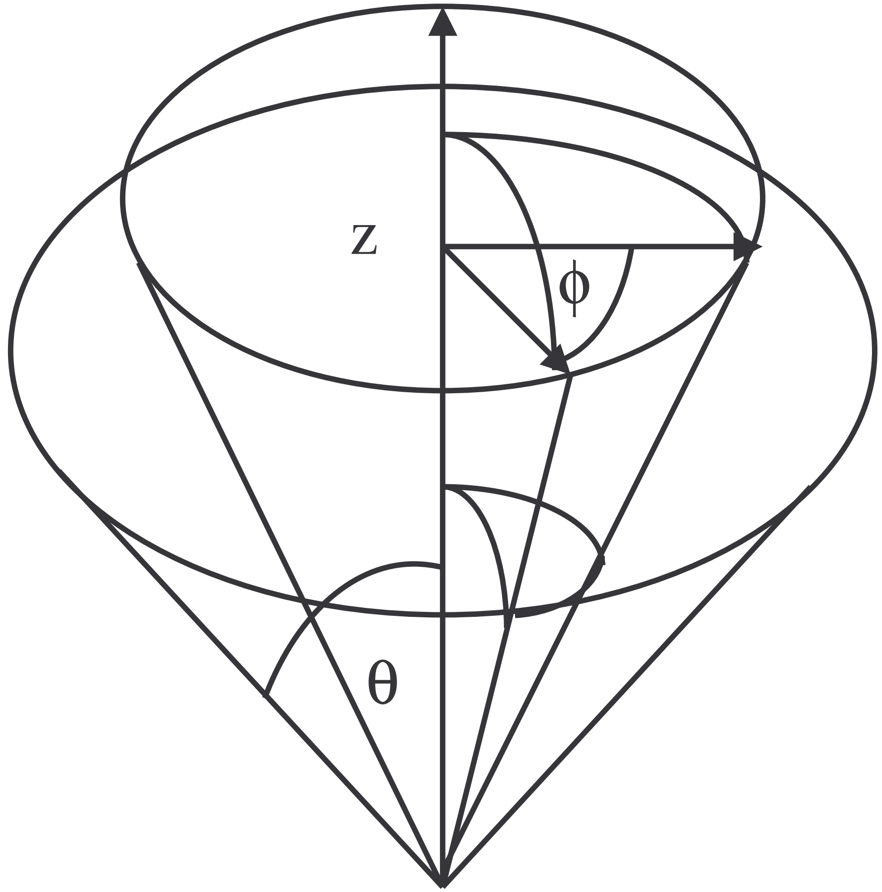
- θ, φ, z-axis
- arbitrary, inhomgeneous spacing possible

θ latitude

φ longitude

z altitude

- Voxel defined by two spheres, to planes and two cones
- Horizontal profile variations possible



Concepts

•Photon unit PU

• wavelength, polarization and intensity

• path attenuation and probability scaling by intensity reduction

•Sun module

•disk with R_E, uniformly distributed PU

•projected onto earth sphere

•initial direction parallel to sun-earth-axis +- solar ap. angle

•CLD if needed (eg for balloon-limb)

•photon path

• path between sun and detector

•composed from segments

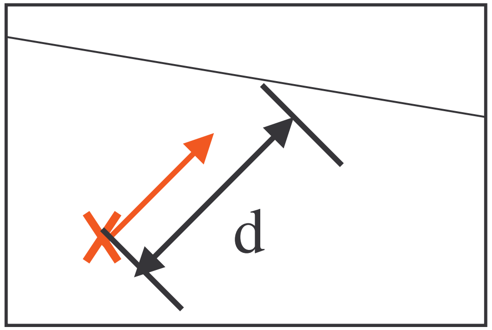
•contains „seen“ SCD, O4 etc.

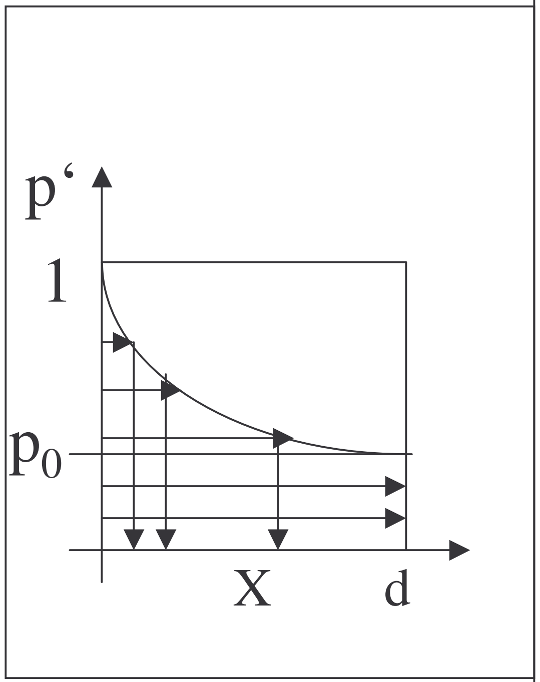
Monte Carlo Approach for MS

- calculation of distance d to next voxel boundary

1. extinctors (Rayleigh, Mie particles) yield probability p(x) for free passage up to x

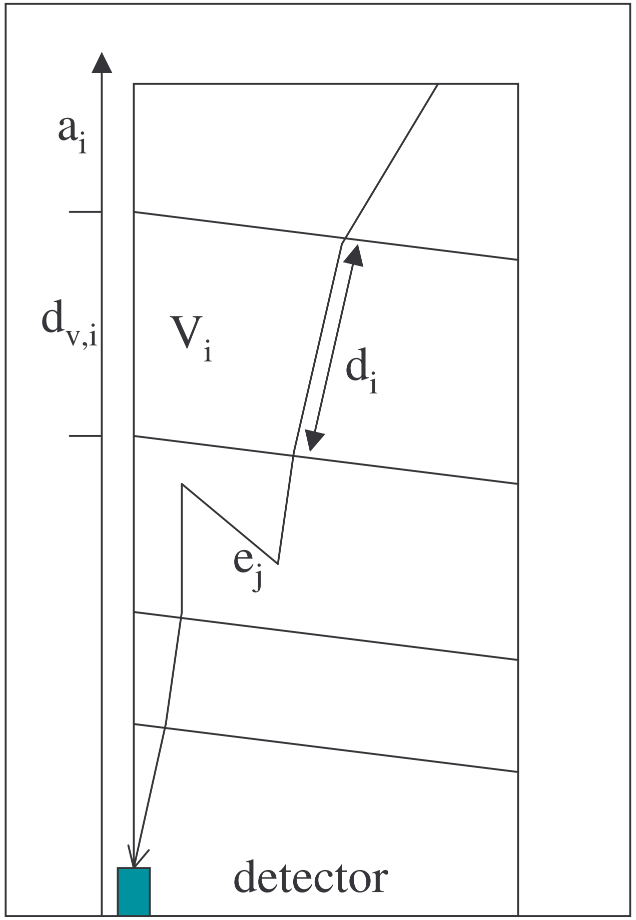
- $p(d)=p_0$ prob. of unscattered passage along d
- map random number p‘ to x by the inverse of function p(x):
- determines location of scattering event [0,d]
- use a second random number to decide between scatterers according to the relative probabilities





Photon path derivation

- random processes govern way through atmosphere
- path composed from the segments d_i within the voxels V_i
- limited each by voxel boundaries and scattering events e_j
- refraction at voxel boundaries
- arbitrary number of e_i possible within each voxel
- molecular absorption calculated analytically
- AMF and Slant OD computed from Intensity with/without absorber
- other path information extractable as well



Output

- SCDs, SODs
- AMFs
- box AMFs and weighting fct. for a specified set of Voxels
- rel. intensities
- geometrical path length
- traversed air column, O4
- number of Rayleigh, Mie and albedo scattering events
- altitudes of first and last scattering event, distance detector-last scattering event
- entry angle of light into atmosphere
- errors as intensity weighted std dev.

Model mode examples

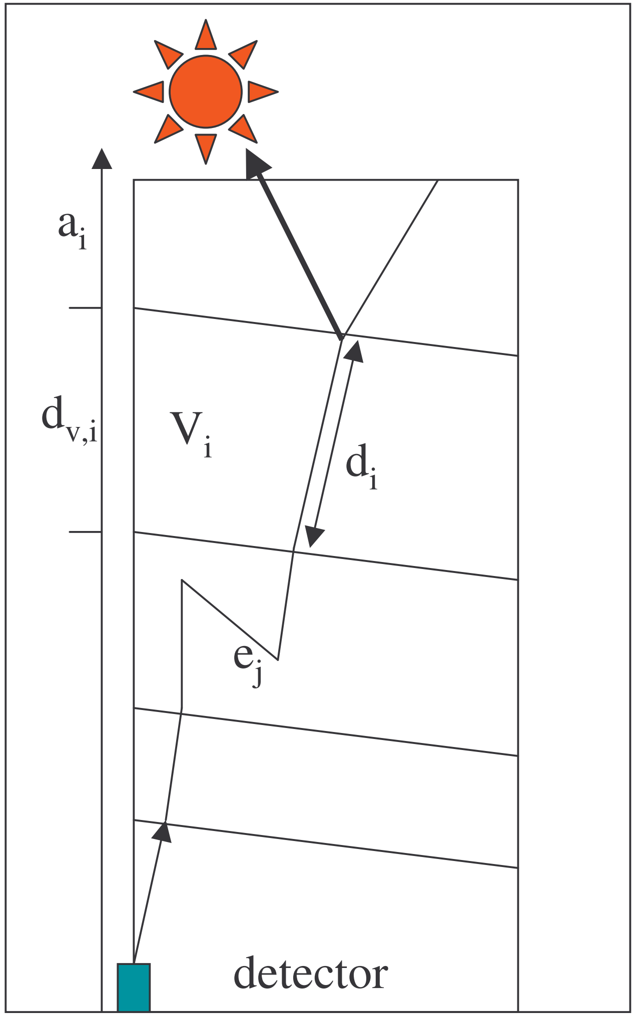
Backward MC (MS):

•PU emerge from a detector in an arbitrary LOS direction

•random numbers govern path through the atmosphere

•refraction at voxel boundaries

•after leaving the atmosphere, the last scattering event is used to force photons into the sun



Model modes examples

Forward Two-stage (SingS):

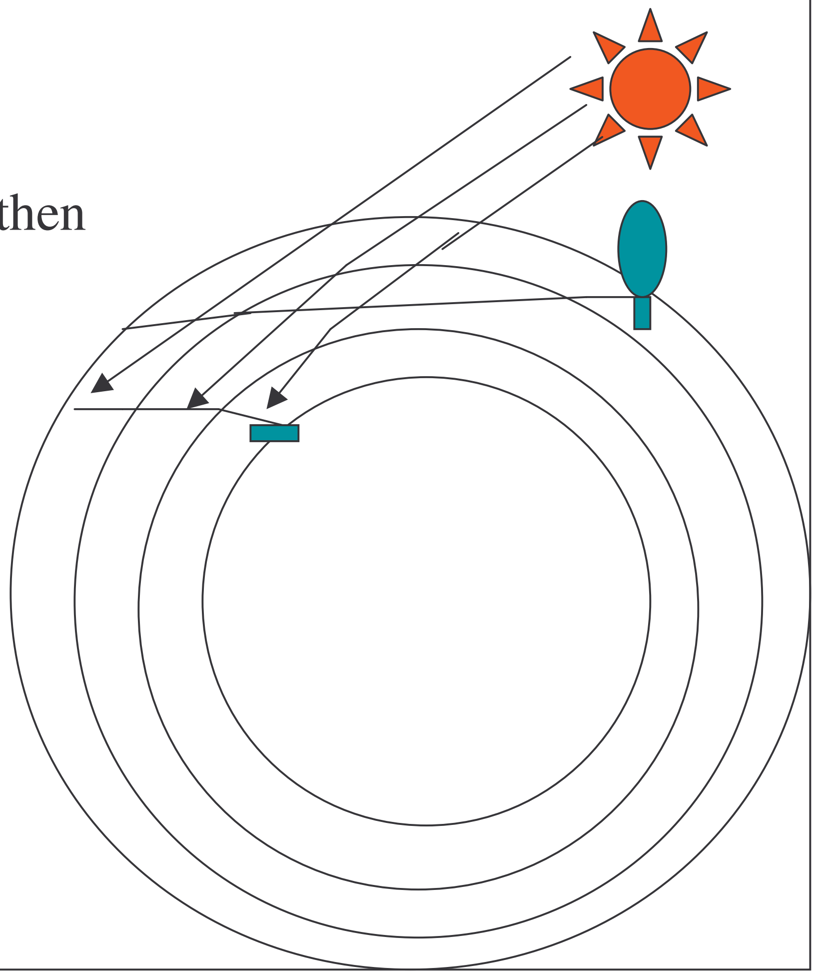
•LOS segment wise probed by parallel incident solar PU, paths bent by refraction

•calculation of path sun-LOS intersection, then from LOS-IS to detector

•one scattering at LOS-IS

•probability = fct(phasefct, scattering ND) accounted for using

•attenuation along paths by Rayleigh and aerosols using Lambert Beer



Model modes examples

Forward Two-stage MC (MS, under dev.):

•Stage 1:

•number N of PU launched from sun at TOA

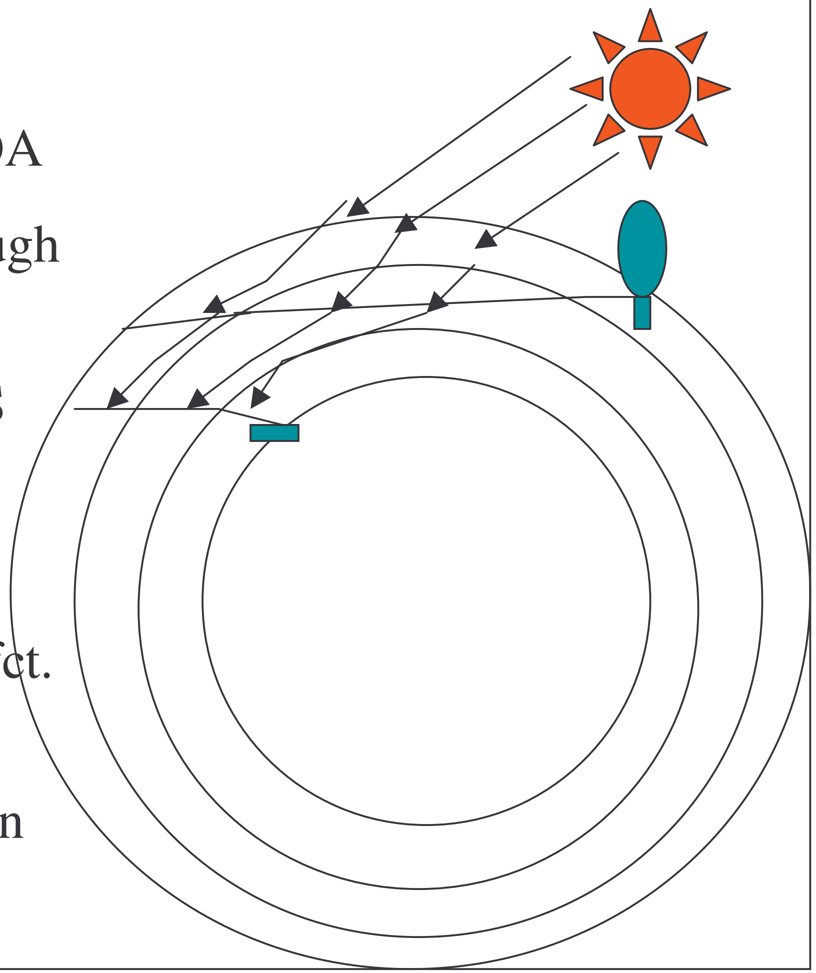
•recording of number of PU passages through cone (array) defined by detector(s)

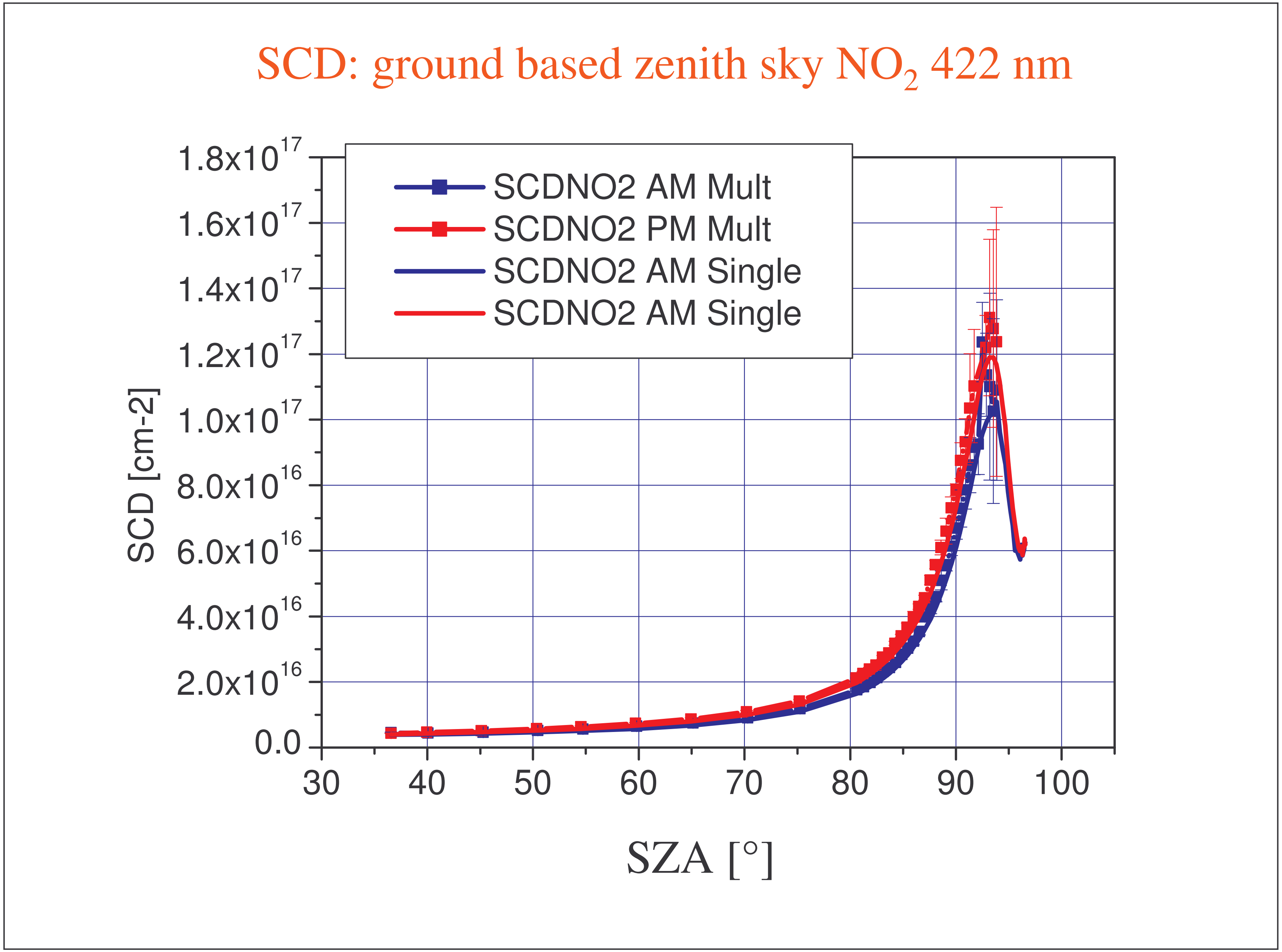
•=>measurement of actinic flux along LOS

•Stage 2:

•redistribution of another N PU along LOS accdg. to scattering centre ND and phase fct.

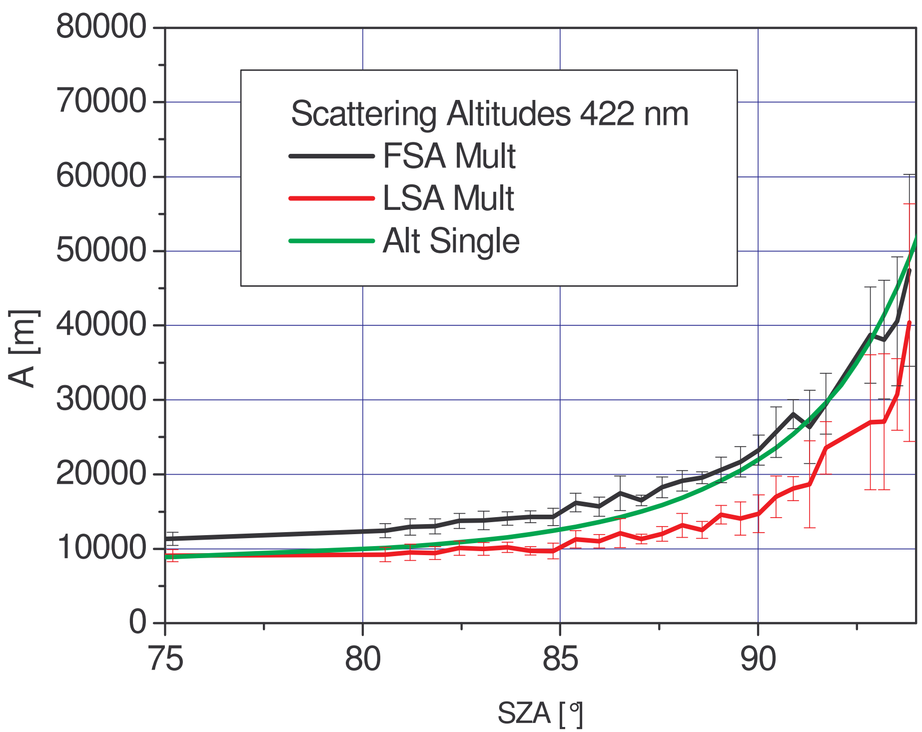
•launch of the PU from the LOS into the detector or Lambert-Beer attenuation like in SingS

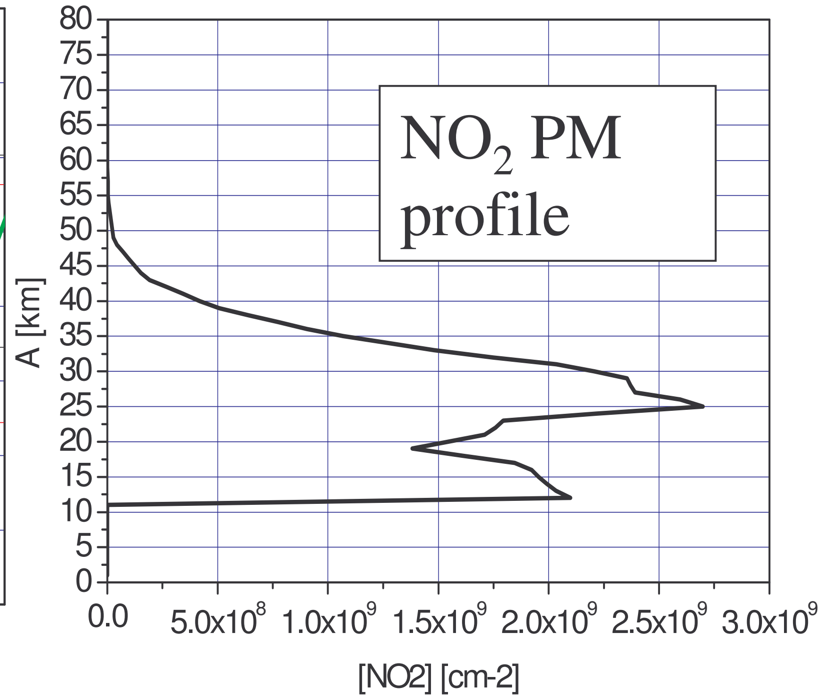




SCD: ground based zenith sky NO2 422 nm
SCDNO2 AM Mult
SCDNO2 PM Mult
SCDNO2 AM Single
SCDNO2 AM Single
1.8x10^17
1.6x10^17
1.4x10^17
1.2x10^17
1.0x10^17
8.0x10^16
6.0x10^16
4.0x10^16
2.0x10^16
0.0
SCD [cm-2]
30
40
50
60
70
80
90
100
SZA [°]

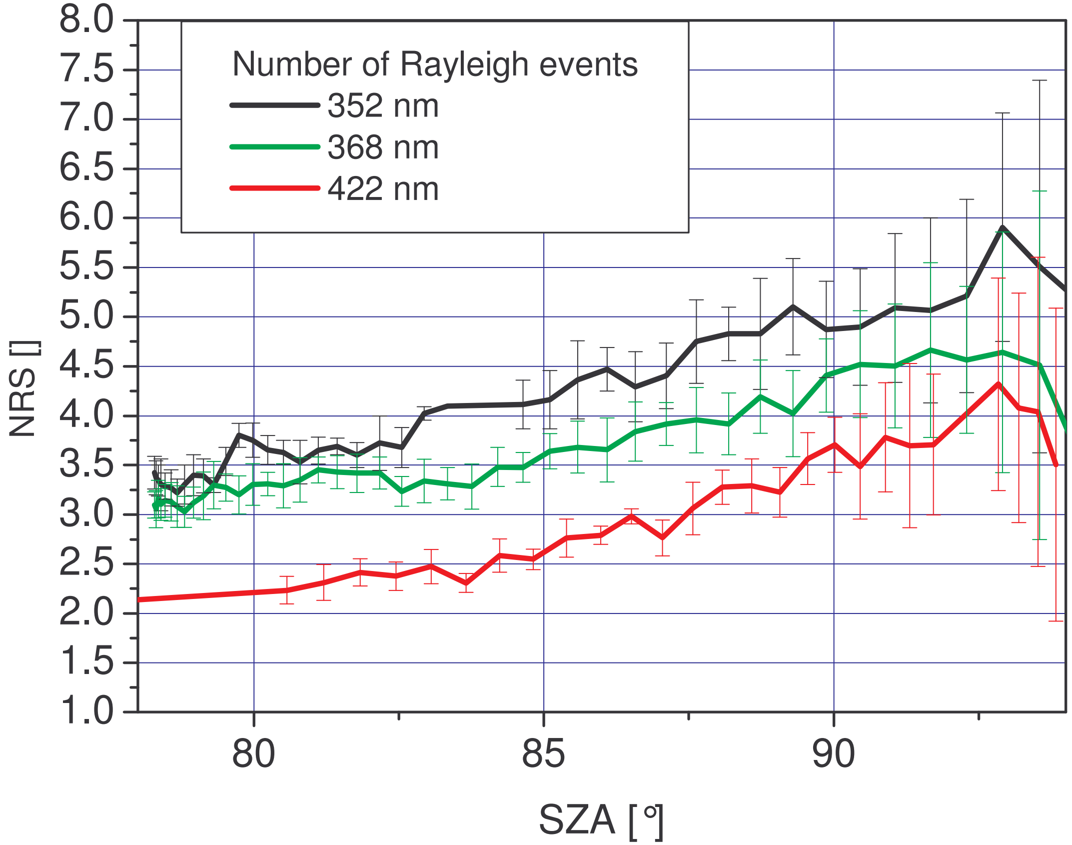
Scattering: NO_2



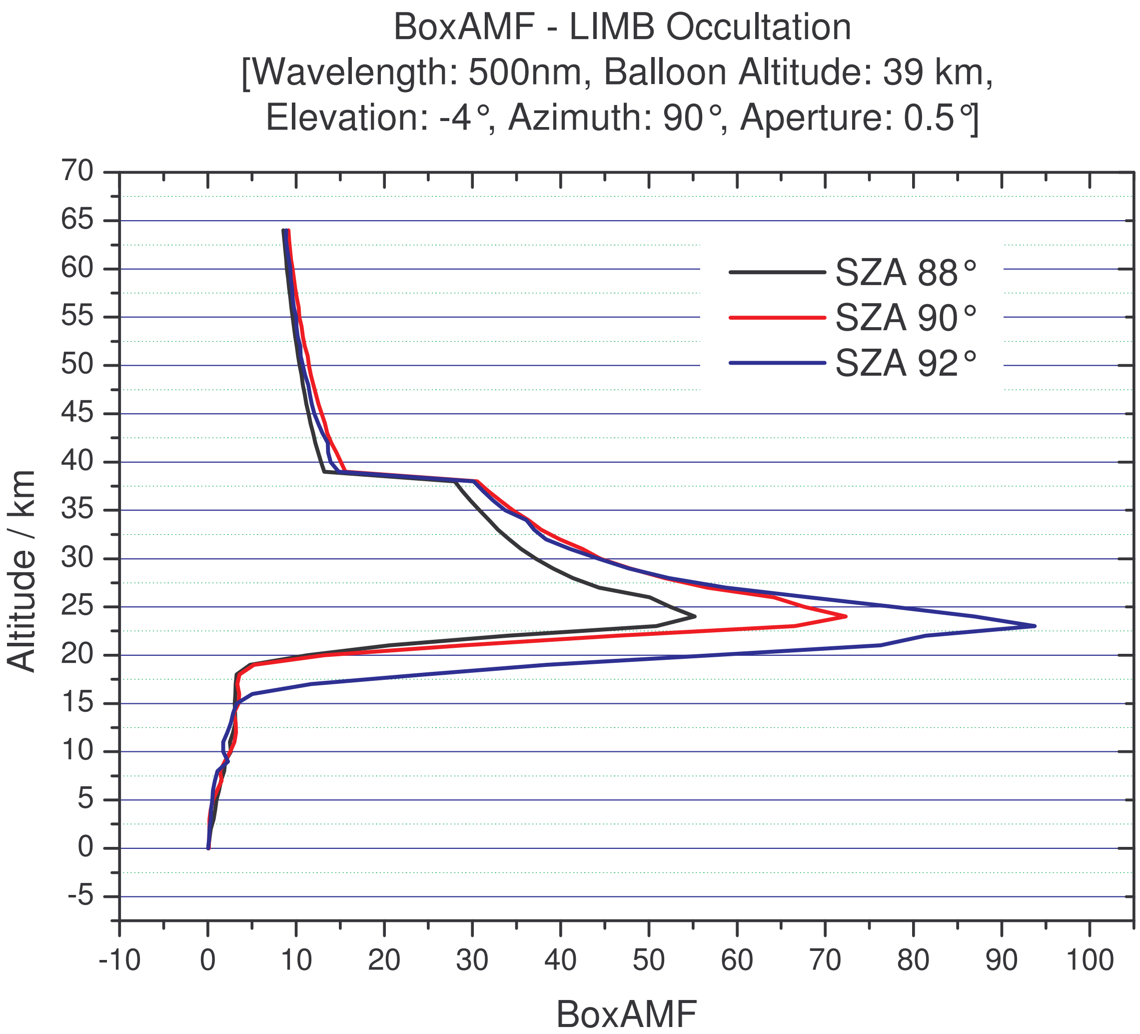


Both scatterings within absorber

Scattering: Number of Events

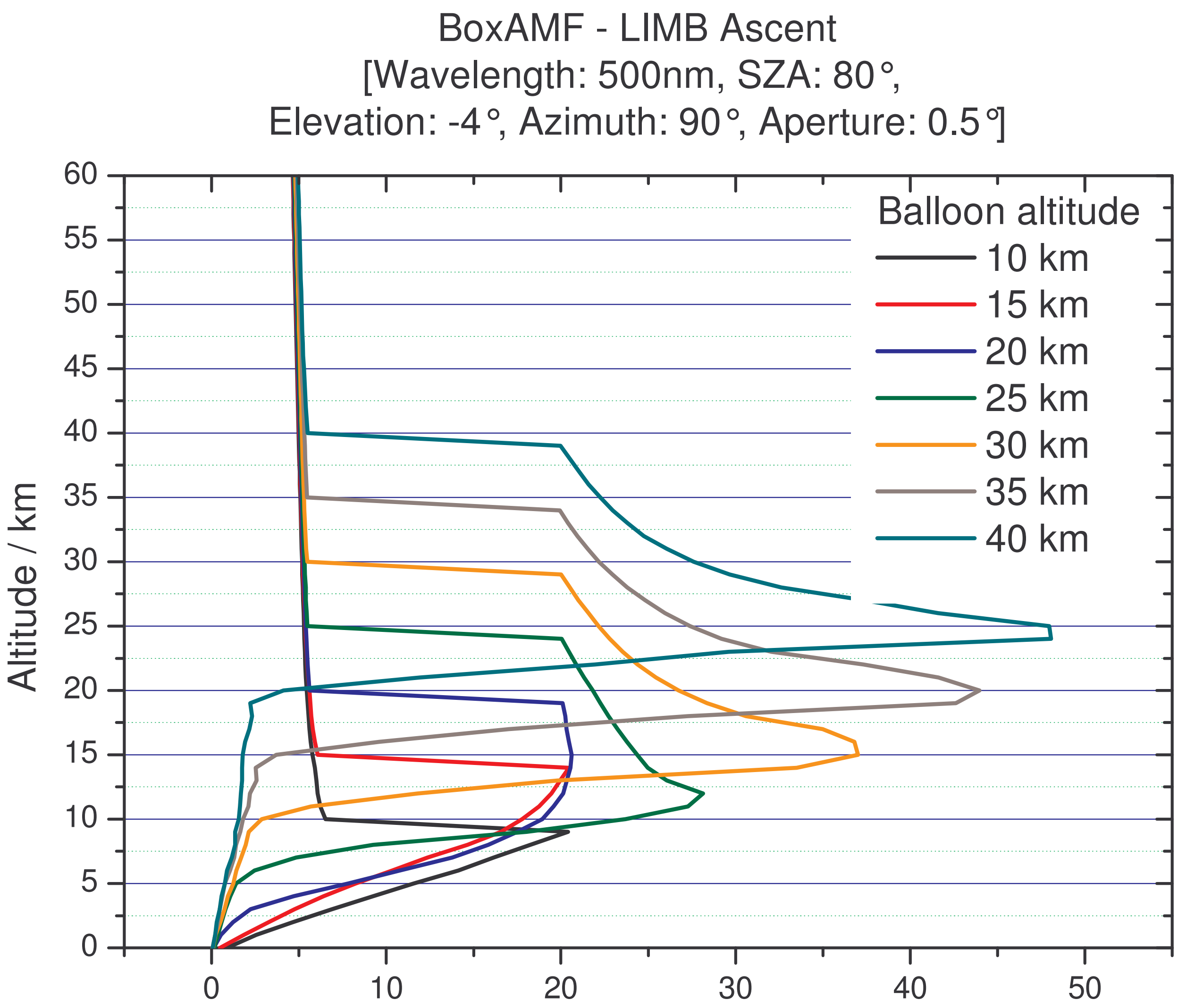


Box-AMFs: Balloon-based DOAS (sensit. studies)



calculated by André Butz with the program

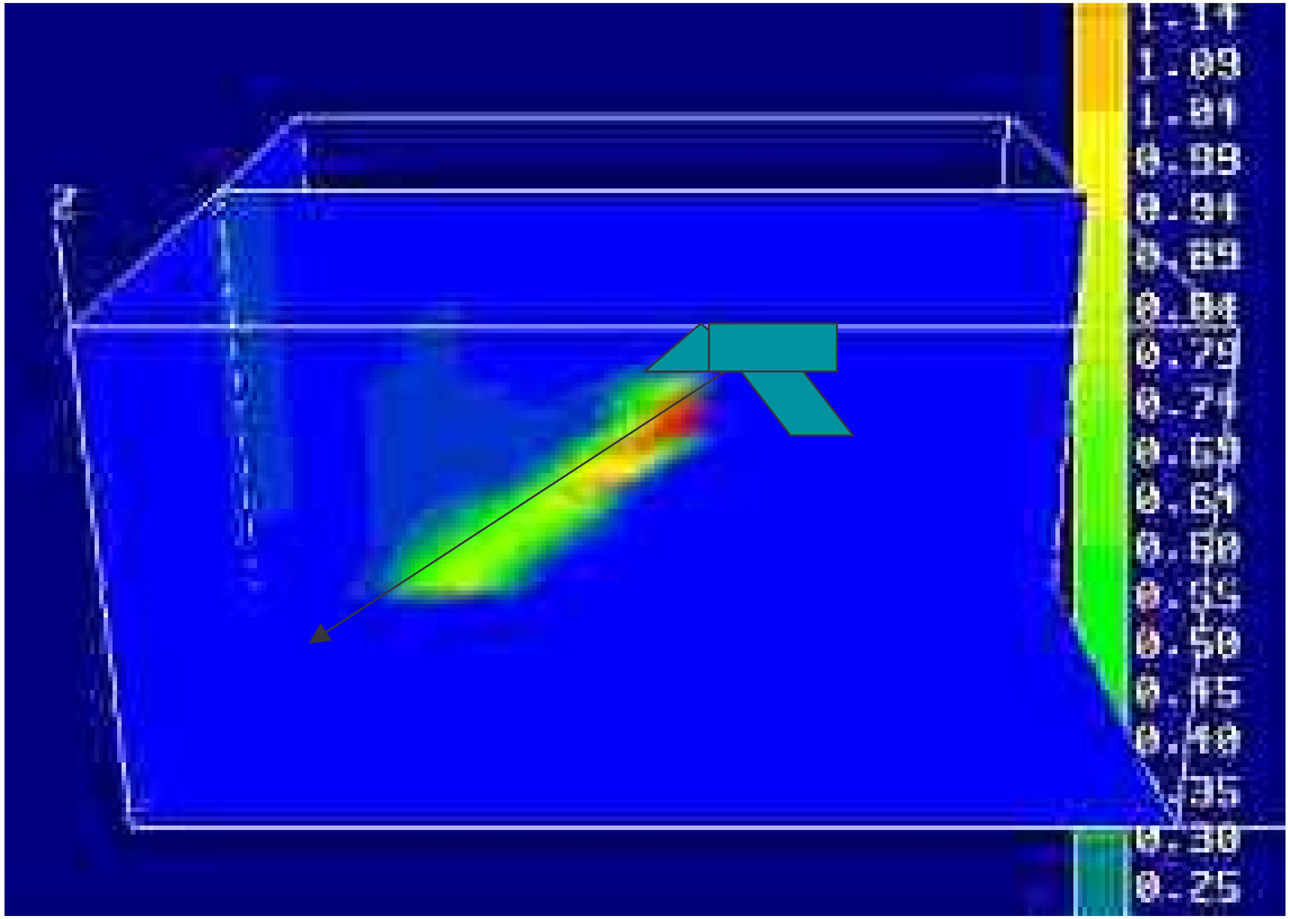
Box-AMFs (sensit. studies)



calculated by André Butz with program BoxAMF

Box-AMFs: Partenavia/FORMAT (sens. studies)

4000 m altitude, LOS 0° azimuth to sun, -20° elevation



Light contribution along LOS in a.u.
360 nm
Rayleigh atm.

image by Thomas Läpple from program output

Outlook

- Implementation of realistic clouds and aerosols
- find ways to increase computational speed (e.g. PLA cards)
- interfaces for SCIA-data
- intercomparison and validation within the QUILT framework
- comparison of radiometric quantities with calibrated spectro-radiometer
- inclusion of basic retrieval modules