Radiation models for the evaluation of the UV radiation at the ground

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Natural **UV radiation at the ground**

--- has strong biological effects

--- must be modelled for

- evaluation of UV measurements
- UV for conditions **without** measurements
- UV in the **future** and in the **past**
- UV sensitivity studies
- UV derived from satellite measurements

--- are photons coming from the Sun passing the atmosphere directly and scattered
extraterrestrial solar radiation

ozone layer (20-30km)

absorption

scattering at
air molecules

absorption by tropospheric
tracegases

Earth surface
reflection

scattering at cloud particles
(waterdroplets, icecrystals)

scattering and absorption by
aerosol particles
Radiative Transfer Equation
Mathematical description of scattering and absorption processes of radiation in the atmosphere
Solution leads to the radiation field

\[ \frac{\mu}{d\tau} \frac{dI(\tau, \mu, \phi)}{d\tau} = I(\tau, \mu, \phi) - \frac{\omega_0}{4\pi} \int I(\tau, \mu', \phi') P(\mu, \varphi; \mu', \varphi') \, d(\mu', \varphi') \]

extinction

multiple scattering

\[ -\frac{\omega_0}{4\pi} \pi F_0 P(\mu, \varphi; \mu_0, \varphi_0) e^{\mu_0 - \tau} \]

scattering
Possible results of modelling

Receiver geometry:

- irradiance on horizontal receiver
- irradiance on arbitrarily oriented receiver
- actinic flux

Wavelength dependency:

- spectral
- biological weighted

(higly variable action spectra)
usual quantity:
erythemal weighted irradiance on horizontal receiver

E_{\text{\(\lambda\)}}(\text{s}(\lambda))

\[ UVI = E_{Ery}[W/m^2] \cdot 40 \left[ m^2/W \right] \]
Models for solar UV radiation

<table>
<thead>
<tr>
<th>Calculation Time</th>
<th>Models</th>
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<tbody>
<tr>
<td>$10^{-2}$</td>
<td>-- simple spectral models</td>
</tr>
<tr>
<td>$10^{0} - 10^{1}$</td>
<td>-- 1-dim, spectral, multiple scattering models</td>
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<tr>
<td></td>
<td>DISORT (Stamnes et al., Appl. Opt., 1988)</td>
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<tr>
<td></td>
<td>STAR (Ruggaber et al., J. Atmosph. Chem., 1994)</td>
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<tr>
<td>$10^{-2}$</td>
<td>-- cloud – algorithmus (CMF)</td>
</tr>
<tr>
<td>$10^{0} - 10^{1}$</td>
<td>-- irradiances on tilted surfaces</td>
</tr>
<tr>
<td>$10^{3} - 10^{4}$</td>
<td>-- 3-dim, spectral, multiple scattering models</td>
</tr>
</tbody>
</table>
extraterrestrial solar radiation

ozone layer (20-30km)

absorption

scattering at air molecules

cloud particles (waterdroplets, ice crystals)

homogeneous cloud layer (1 dim)

scattering and absorption by aerosol particles

Earth surface

reflection
### Input parameters for UV modelling:

**Astronomical parameters**
- extraterrestrial solar irradiance
- Sun-Earth distance
- Solar Zenith Angle $SZA = \text{relative airmass } m_l$

**Meteorological parameters**
- Ozone
- Aerosol (amount & type >> optical depth AOD & SSA)
- Surface albedo
- Altitude above sea level
- Clouds (amount & type, cloud in front or besides Sun)
- Trace gases
Optical thickness of atmospheric parameters

Optische Dicke von Wolken:
<1 bis >100
average cloud ~20
Clear atmosphere,
3% albedo,
Cloud free

Koepke et al. (2002)
Recent Res. Devel.
Photochem. Photobiol.,
6: 11-34
Aerosol effect (UVI reduction against conditions with background aerosol)

Koepke, 2004
Effect of surface albedo

Increase of spectral UV-irradiance against that for a black surface (cloud free conditions)

Altitude effect in % / km

Background Altitude Effect: 7% / km

Pfeifer et al., 2006, J. Geophys. Res.
Effects of clouds (UVI reduction against cloud-free conditions)

CMF =
Cloud modification factor =
\[
\frac{\text{UVI cloudy sky}}{\text{UVI sky without clouds}}
\]

Koepke et al.,
2002,
after different authors

Cloud cover in octas

CMF

0.0
0.2
0.4
0.6
0.8
1.0
1.2

0 1 2 3 4 5 6 7 8

Cloud cover in octas

CMF

0.0
0.2
0.4
0.6
0.8
1.0
1.2

0 1 2 3 4 5 6 7 8
CMF derived from UVI measurements
for cloudy and clear conditions
or modelled for the clear atmosphere
to get the same O3 and aerosol conditions

Description of clouds for practical use to get CMF:

Cloudiness:    x/8
Cloudiness for low, medium, high clouds
Cloud in front of the Sun
Solar global irradiance

Schwander et al., 2002
CMF_{UV} as function of CMF_{solar}

den Outer et al., 2005, J.Geophys.Res.
Human skin is **not** horizontal

$$\cos(SZ\text{Askin})$$

Placzek 2003
Tilt modification factors $\text{TMF} = \frac{\text{UVI}_{\text{tilt}}}{\text{UVI}_{\text{hor}}}$ (azimuth receiver = azimuth Sun)

- **Skiing conditions:** Fresh snow, 3000 m, Clear atmosphere
- **Beach conditions:** Sand, 0 m, Clear atmosphere
- **Summer conditions:** Meadow, 500 m, Average turbidity

UVI on a surface tilted towards the Sun (azimuth receiver = azimuth Sun)

Munich, clear atmosphere, no obstruction of sun or sky, ozone: mean monthly minimum; SZA: noon 15th month
UV irradiances on tilted surfaces: modelled

**STAR**
System of Transfer of Atmospheric Radiation
Koepke et al., 2004

**Radoninc**
Radiation on Inclined Surfaces

**Skop**
Sky Obstruction program
Typical *street canyon* in Munich
Diurnal variation of UVI on a surface tilted, but azimuth averaged (Moving person) Street canyon, orientation North - South

Summer, Munich, clear atmosphere, ozone 330 DU
Sun and shadow in human environment
Human environment  (Munich, English Garden)
Conclusion

Modelling of UV radiation is necessary for
• evaluation and sensitivity studies
• conditions without measurements (future, past)

Modelling of UV radiation is possible for
• any biological UV-weighting
• all different radiation quantities

Different computer codes exist for Modelling of UV radiation
• Libradtran (UVspec, Mystic)
• STAR
• Disort

Uncertainty of modelled UV radiation results from
• knowledge, uncertainty of atmospheric, environmental conditions
• not from mathematical quality of radiative transfer models
Mille grazie!