Scientific Challenges of UV-B Forecasting

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- International activities and the UV Index
- UV Index definition and forecasting requirements
- Challenges in calculation of the radiation transfer
  - effects of aerosols (relation to GEMS), of altitude, and of albedo
  - cloud modification factor
- Example, products, verification
- Conclusion
UNCED 1992, Agenda 21, and INTERSUN

Agenda 21: Undertake as a matter of urgency
• research on the effects on human health of increasing UV reaching the ground due to ozone depletion
• efforts to mitigate the effects on human beings

In response to Agenda 21, WHO and further organisations established INTERSUN the Global UV Project:

Objective: Primary prevention; Priority Activities:
• Filling gaps in scientific knowledge
• Assessing and quantifying health risks
• Promoting sun protection
• Promoting the UV Index
UV Index

In 1994 introduced by WMO, WHO, ICNIRP, UNEP to

• describe the level of solar UV radiation reaching the ground by means of a simple physical quantity

Objective:

• raise public awareness of the risk of excessive exposure to UV and the need to adopt protective measures

• serve as an educational tool to promote sun protection
UV Index: Biologically weighted physical quantity

UV Index Definition

$$\text{UV Index} = k_{er} \int E(\lambda) \cdot s_{er}(\lambda) \cdot d\lambda$$

$$E(\lambda) \ [W \ m^{-2} \ nm^{-1}] = \frac{400 \ nm}{280 \ nm}$$

$$\lambda, d\lambda \ [nm] = \text{spectral solar irradiance at the earth surface}$$

$$k_{er} = \text{wavelength and wavelength interval}$$

$$s_{er}(\lambda) = 40 \ [m^2 \ W^{-1}]$$

$$\text{CIE (1987) erythema reference action spectrum}$$

The UV Index is defined in reference to a horizontal surface.
Requirements in UV Index forecasting and reporting

WMO

• to take into account cloud cover and other relevant environmental variables (surface albedo, aerosols)
• to report to the public the daily maximum value, whenever it occurs

COST-713 on “UV-B forecasting” recommends additionally:

• to forecast total ozone by global dynamical models, including chemistry effects and data assimilation techniques.
• to include aerosol optical depth variable in space and season.
• to model the UV Index by a multiple scattering algorithm.
Challenges in UV Index forecasting

The challenges to accept in UV forecasting are of operational nature:

- forecasting not only for local noon
- fast calculation of radiation transfer accounting for
  - aerosol optical depth
  - aerosol absorption (single scattering albedo)
  - altitude effects
  - surface albedo
  - clouds
Radiation Transfer for clear sky conditions

Large Scale UV Index (ls_UVI)

Realised by Lookup Tables (LUT) for
- 12 months
- 5 zonal belts per hemisphere

Resolution 1° in solar zenith angle (SZA), 10 DU in total ozone (TOZ)

Range: 0 - 14 (mean sea level)

Vertical distribution of ozone and temperature: effects < 3 %
Adjusting for variable atmospheric conditions and altitude

\[ \text{UVI} = \text{ls}_\text{UVI}(\text{SZA}, \text{TOZ}) \]

\* \( f_{\text{aerosol}}(\text{AOD}, \text{SSA}, \text{SZA}) \)

\* \( f_{\text{altitude}}(\text{AOD}, \text{SSA}, \text{SZA}, z) \)

\* \( f_{\text{albedo}}(\text{ALB}, \text{SZA}, z) \)

[UV Index clear sky]

\* \( f_{\text{clouds}}(\text{cloud_cover}, \text{cloud_type}[\text{, sw-rad}]) \)
Aerosol effects: \( f_{\text{aerosol}}(\text{AOD}, \text{SSA}, \text{SZA}) \)

Aerosol effects modelled by
- set type: stratosphere (>12 km)
- set type: free troposphere (<12 km)
- variable types: (0-3 km)

Type of relative aerosol profile:
- volcanic background conditions
Phase function, asymmetry factor, and SSA are defined via the aerosol types. Effects of varying profiles <3%
Aerosol effects

June, mean sea level ozone 300 DU, clear sky

- mc_0.1
- mc_0.4
- mc_0.7
- ca_0.1
- ca_0.4
- ca_0.7
- ur_0.1
- ur_0.4
- ur_0.7

Aerosol type, AOD 550

UV Index vs. solar zenith angle, °
Aerosol effects: $f_{\text{aerosol}}(\text{AOD, SSA, SZA})$

Accounting for aerosol effects:
- influence of AOD increases with decreasing SSA
- dependence on SZA is low, strongest at $\sim 60^\circ$

Large-scale UV Index
Adjusted to variable aerosol by a factor dependent on
- AOD, SSA, SZA

UVI, maximum abs. error: 0.05
Aerosol effects: $f_{\text{aerosol}}(\text{AOD, SSA, SZA})$

Accounting for aerosol effects:
- influence of AOD increases with decreasing SSA
- dependence on SZA is low, strongest at ~60°

Large-scale UV Index
Adjusted to variable aerosol by a factor dependent on
- AOD, SSA, SZA

UVI, maximum abs. error: 0.21
Seasonal and Regional Variations of AOD and SSA

Accounting for seasonal changes in AOD at 550 nm:

- NASA MOD08_M3, original
- Reduction of pixel mean with increased standard deviation
- Polar regions: set background from GADS and further reading
- Fill data gaps by NASA TOMS AOD, 1979 - 2001
- Average of same months

“Climatology”: Average of same months and slight smoothing, April
Seasonal and Regional Variations of AOD and SSA

Accounting for semi-annual changes in single scattering albedo (SSA) at 300 nm:

- Global Aerosol Data Set (GADS), University Munich
- spatial resolution: 5° * 5°

SSA 300 nm (relative Humidity 70%):
GADS limited to SSA > 0.887: Summer
Adjusting for Altitude: $f_{\text{altitude}}(\text{AOD}, \text{SSA}, \text{SZA}, z)$

Altitude Effect = relative difference in the irradiance between two altitudes, scaled to 1 km.

Parameterisation formula:

$$\ln(\text{UVI}_z / \text{UVI}_{\text{msl}}) = \text{Ray}(\text{SZA}, z) + \text{Aer}(\text{SZA}, z, \text{AOD}, \text{SSA})$$

UVI, maximum abs. error: 0.04

http://www.dwd.de/PROMOTE/  http://www.uv-index.de
Adjusting for Altitude: $f_{\text{altitude}}(\text{AOD}, \text{SSA}, \text{SZA}, z)$

Altitude effects of aerosol:
- increasing with increasing AOD
- strongly increasing with decreasing SSA
- slightly dependent on SZA with a maximum at about 50 to 70°

**Effect:** UVI increase, % per 1 km aerosol “ca”, AOD=0.20: 7 - 8%
aerosol “ca”, AOD=0.40: 10 - 11%
aerosol “ur”, AOD=0.40: 14 - 16%

UVI, maximum abs. error: 0.21
Adjusting for Surface Albedo 
\( \text{f}_{\text{albedo}}(\text{ALB}, \text{SZA}, z) \)

Local surface albedo defined by
\[
\text{alb} [\%] = 100. * (\text{irr} \uparrow / \text{irr} \downarrow)
\]

UV surface albedo generally is low, exception:
- snow/ice, fresh : ~95 %
- old/wet : ~70 %

The irradiance at a receiver is determined by the albedo of an area of up to 30 km².

Effects on UVI: 0 - 40 %
Cloud Modification Factor (CMF)

CMF = \( \frac{UVI_{\text{cloudy}}}{UVI_{\text{clear sky}}} \)

Function of
- cloud cover
- cloud type
- short-wave irradiance

Challenging is the high micro- and macro-physical variability in space and in time

Range of CMF: 1.00 - 0.20
Examples of UV Index Calculation and Derived Products

Radiation transfer:
- lookup tables depending on
  - solar zenith angle
  - total column ozone

Resolution:
- 12 month
- 10 zonal belts

Set: clear sky, albedo, mean sea level, AOD/SSA
Variable: total column ozone, solar zenith angle

UV Index clear sky, 06.07.05 00:00 UTC period: +15 h

http://www.dwd.de/PROMOTE/  http://www.uv-index.de
Examples of UV Index Calculation and Derived Products

Radiation transfer:
- lookup tables

Adjustment for:
- aerosol optical depth (AOD)
- single scattering albedo (SSA)

Set: clear sky, albedo, mean sea level
Variable: AOD/SSA

UV Index clear sky, 06.07.05 00:00 UTC period: +15 h

http://www.dwd.de/PROMOTE/  http://www.uv-index.de
Examples of UV Index Calculation and Derived Products

Radiation transfer:
- lookup tables

Adjustment for
- AOD and SSA
- altitude a.m.s.l

Set: clear sky, albedo
Variable: AOD/SSA, topography

UV Index clear sky, 06.07.05 00:00 UTC period - +15 h

http://www.dwd.de/PROMOTE/
http://www.uv-index.de
Examples of UV Index Calculation and Derived Products

Radiation transfer:
- lookup tables

Adjustment for
- AOD and SSA
- altitude a.m.s.l
- albedo

UV Index clear sky

Set : clear sky
Variable : AOD/SSA, topography, albedo

UV Index clear sky, 06.07.05 00:00 UTC period - 15 h
Examples of UV Index Calculation and Derived Products

Radiation transfer:
- lookup tables

Adjustment for
- AOD and SSA
- altitude a.m.s.l
- albedo
- UV Index clear sky
- CMF
- UV Index cloudy

Set: ---
Variable: AOD/SSA, topography, albedo, clouds

UV Index cloudy, 08.07.05 00:00 UTC. Period: +15 h

http://www.dwd.de/PROMOTE/
http://www.uv-index.de
Examples of UV Index Calculation and Derived Products

**Daily Maximum of UV Index clear sky**
- reassembly of hourly data

**Antarctic Ozone Hole:**
- additional effects:
  - sun elevation mid spring
  - albedo of snow/ice

http://www.dwd.de/PROMOTE/
http://www.uv-index.de
Examples of UV Index Calculation and Derived Products

Daily Maximum of UV Index cloudy
- reassembly of hourly data

Antarctic Ozone Hole:
additional effects:
- sun elevation mid spring
- albedo of snow/ice
- in essential parts masked by clouds

Daily maximum of UV Index cloudy, 28.10.04 00:00 UTC period=+12 h
Verification of forecasted UV Index

Measured UV Index: FMI COST-713 UV Index data base: 21.11.03

- sites merged: 11
- co-ordinates: Europe
- time series: 01.05. - 30.09.2003
- measurements: 1175

<table>
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<th>Parameter</th>
<th>Measured</th>
<th>Forecasted</th>
<th>Bias</th>
<th>RMS Error</th>
<th>Correlation</th>
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<tbody>
<tr>
<td>UVI ozone, DU</td>
<td>5.23</td>
<td>5.50</td>
<td>+0.27</td>
<td>+8.1</td>
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<tr>
<td>measured mean</td>
<td>323.6</td>
<td>331.7</td>
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<tr>
<td>forecasted mean</td>
<td>323.6</td>
<td>331.7</td>
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</tbody>
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Acknowledgement: Thanks to all contributors and to FMI hosting the data base
Conclusion

• Aerosols can influence the UV Index up to an amount comparable to that of day to day changes in ozone column.
• UV Index forecasting is prepared to account for aerosol effects.
• GEMS could be a source providing operationally:
  • current values of aerosol optical depth and aerosol type as near real time assimilated fields of aerosol properties having a global coverage.
  • future: forecasts.
• The largest uncertainties are due to cloudiness.
  • Improvements for the future will be possible.
  • COST-726 on UV climatology and trends can contribute to more accurate Cloud Modification Factors.

WMO EC-LV (2003) approves a UV Index function for RSMC Offenbach