A handbook of theory and recipes

R for Photobiology

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Pedro J. Aphalo,
Andreas Albert
T. Matthew Robson
and
Titta Kotilainen

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Preface

This is just a very early draft of a handbook that will accompany the release of the suite of R packages for photobiology (r4photobiology).

1. Acknowledgements

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List of abbreviations and symbols

For quantities and units used in photobiology we follow, as much as possible, the recommendations of the Commission Internationale de l'Éclairage as described by (Sliney 2007).

Symbol	Definition
α	absorptance (%).
Δe	water vapour pressure difference (Pa).
ϵ	emittance ($\mathrm{W\,m^{-2}}$).
λ	wavelength (nm).
θ	solar zenith angle (degrees).
ν	frequency (Hz or $\mathrm{s^{-1}}$).
ρ	reflectance (%).
σ	Stefan-Boltzmann constant.
τ	transmittance (%).
χ	water vapour content in the air ($\mathrm{g\,m^{-3}}$).
A	absorbance (absorbance units).
ANCOVA	analysis of covariance.
ANOVA	analysis of variance.
BSWF	biological spectral weighting function.
c	speed of light in a vacuum.
CCD	charge coupled device, a type of light detector.
CDOM	coloured dissolved organic matter.
CFC	chlorofluorocarbons.
c.i.	confidence interval.
CIE	Commission Internationale de l'Éclairage; or erythemal action spectrum standardized by CIE.
CTC	closed-top chamber.
DAD	diode array detector, linear light detector based on photodiodes.
DBP	dibutylphthalate.
DC	direct current.
DIBP	diisobutylphthalate.
DNA(N)	UV action spectrum for 'naked' DNA.
DNA(P)	UV action spectrum for DNA in plants.
DOM	dissolved organic matter.
DU	Dobson units.
e	water vapour partial pressure (Pa).
E	(energy) irradiance ($\mathrm{W\,m^{-2}}$).
$E(\lambda)$	spectral (energy) irradiance ($\mathrm{W\,m^{-2}\,nm^{-1}}$).
E_0	fluence rate, also called scalar irradiance ($\mathrm{W\,m^{-2}}$).
ESR	early stage researcher.
FACE	free air carbon-dioxide enhancement.
FEL	a certain type of 1000 W incandescent lamp.
FLAV	UV action spectrum for accumulation of flavonoids.
FWHM	full-width half-maximum.
GAW	Global Atmosphere Watch.
GEN	generalized plant action spectrum, also abreviated as GPAS (Caldwell 1971).
GEN(G)	mathematical formulation of GEN by (Green et al. 1974) .
GEN(T)	mathematical formulation of GEN by (Thimijan et al. 1978).

h	Planck's constant.
h'	Planck's constant per mole of photons.
H	exposure, frequently called dose by biologists ($\mathrm{kJ\,m^{-2}\,d^{-1}}$).
H^{BE}	biologically effective (energy) exposure ($\mathrm{kJ\,m^{-2}\,d^{-1}}$).
$H^{\mathrm{BE}}_{\mathrm{p}}$	biologically effective photon exposure ($\mathrm{mol\,m^{-2}\,d^{-1}}$).
HPS	high pressure sodium, a type of discharge lamp.
HSD	honestly signifcant difference.
k_{B}	Boltzmann constant.
L	radiance ($\mathrm{W\,sr^{-1}\,m^{-2}}$).
LAI	leaf area index, the ratio of projected leaf area to the ground area.
LED	light emitting diode.
LME	linear mixed effects (type of statistical model).
LSD	least significant difference.
n	number of replicates (number of experimental units per treatment).
N	total number of experimental units in an experiment.
N_{A}	Avogadro constant (also called Avogadro's number).
NIST	National Institute of Standards and Technology (U.S.A.).
NLME	non-linear mixed effects (statistical model).
OTC	open-top chamber.
PAR	photosynthetically active radiation, 400–700 nm. measured as energy or photon irradiance.
PC	polycarbonate, a plastic.
PG	UV action spectrum for plant growth.
PHIN	UV action spectrum for photoinhibition of isolated chloroplasts.
PID	proportional-integral-derivative (control algorithm).
PMMA	polymethylmethacrylate.
PPFD	photosynthetic photon flux density, another name for PAR photon irradiance (Q_{PAR}).
PTFE	polytetrafluoroethylene.
PVC	polyvinylchloride.
q	energy in one photon ('energy of light').
q'	energy in one mole of photons.
Q	photon irradiance ($\mathrm{mol\,m^{-2}\,s^{-1}}$ or $\mathrm{\mu mol\,m^{-2}\,s^{-1}}$).
$Q(\lambda)$	spectral photon irradiance ($\mathrm{mol\,m^{-2}\,s^{-1}\,nm^{-1}}$ or $\mathrm{\mu mol\,m^{-2}\,s^{-1}\,nm^{-1}}$).
r_0	distance from sun to earth.
RAF	radiation amplification factor (nondimensional).
RH	relative humidity (%).
s	energy effectiveness (relative units).
$s(\lambda)$	spectral energy effectiveness (relative units).
s^{p}	quantum effectiveness (relative units).
$s^{\mathrm{p}}(\lambda)$	spectral quantum effectiveness (relative units).
s.d.	standard deviation.
SDK	software development kit.
s.e.	standard error of the mean.
SR	spectroradiometer.
t	time.
T	temperature.
TUV	tropospheric UV.
U	electric potential difference or voltage (e.g. sensor output in V).
UV	ultraviolet radiation ($\lambda = 100$–400 nm).
UV-A	ultraviolet-A radiation ($\lambda = 315$–400 nm).
UV-B	ultraviolet-B radiation ($\lambda = 280$–315 nm).
UV-C	ultraviolet-C radiation ($\lambda = 100$–280 nm).

UV^{BE}	biologically effective UV radiation.
UTC	coordinated universal time, replaces GMT in technical use.
VIS	radiation visible to the human eye ($\approx$ 400–700 nm).
WMO	World Meteorological Organization.
VPD	water vapour pressure deficit (Pa).
WOUDC	World Ozone and Ultraviolet Radiation Data Centre.

Part I.

Theory behind calculations

Part II.

Tools used for calculations

Part III.

Cookbook of calculations

```
incl_ckbk <- FALSE
```

Part IV.

Data acquisition and modelling

Part V.

Catalogue of example data

Part VI.

Optimizing computation speed

1.

Further reading

Bibliography

Albert, A. and P. Gege (2006). “Inversion of irradiance and remote sensing reflectance in shallow water between 400 and 800 nm for calculations of water and bottom properties”. In: *Applied Optics* 45, pp. 2331–2343. DOI: 10.1364/AO.45.002331.

Albert, A. and C. D. Mobley (2003). “An analytical model for subsurface irradiance and remote sensing reflectance in deep and shallow case-2 waters”. In: *Optics Express* 11.22, pp. 2873–2890. URL: http://www.opticsexpress.org/abstract.cfm?URI=OPEX-11-22-2873.

Allen, L. H., H. W. Gausman, and W. A. Allen (1975). “Solar Ultraviolet Radiation in Terrestrial Plant Communities”. In: *Journal of Environmental Quality* 4.3, pp. 285–294. DOI: 10.2134/jeq1975.00472425000400030001x.

Anderson, J., W. Chow, and D. Goodchild (1988). “Thylakoid Membrane Organisation in Sun-/Shade Acclimation”. In: *Functional Plant Biology* 15, pp. 11–26. DOI: 10.1071/PP9880011.

Aphalo, P. J. (2003). “Do current levels of UV-B radiation affect vegetation? The importance of long-term experiments”. In: *New Phytologist* 160. Invited commentary, pp. 273–276. DOI: 10.1046/j.1469-8137.2003.00905.x.

Aphalo, P. J., A. Albert, L. O. Björn, A. R. McLeod, T. M. Robson, and E. Rosenqvist, eds. (2012). *Beyond the Visible: A handbook of best practice in plant UV photobiology*. 1st ed. COST Action FA0906 “UV4growth”. Helsinki: University of Helsinki, Department of Biosciences, Division of Plant Biology, pp. xxx + 174. ISBN: ISBN 978-952-10-8363-1 (PDF), 978-952-10-8362-4 (paperback). URL: http://hdl.handle.net/10138/37558.

Aphalo, P. J., A. Albert, L. O. Björn, L. Ylianttila, F. L. Figueroa, and P. Huovinen (2012). “Introduction”. In: *Beyond the Visible: A handbook of best practice in plant UV photobiology*. Ed. by P. J. Aphalo, A. Albert, L. O. Björn, A. R. McLeod, T. M. Robson, and E. Rosenqvist. 1st ed. COST Action FA0906 “UV4growth”. Helsinki: University of Helsinki, Department of Biosciences, Division of Plant Biology. Chap. 1, pp. 1–33. ISBN: ISBN 978-952-10-8363-1 (PDF), 978-952-10-8362-4 (paperback). URL: http://hdl.handle.net/10138/37558.

Aphalo, P. J., A. Albert, A. R. McLeod, A. Heikkilä, I. Gómez, F. López Figueroa, T. M. Robson, and Å. Strid (2012). “Manipulating UV radiation”. In: *Beyond the Visible: A handbook of best practice in plant UV photobiology*. Ed. by P. J. Aphalo, A. Albert, L. O. Björn, A. R. McLeod, T. M. Robson, and E. Rosenqvist. 1st ed. COST Action FA0906 “UV4growth”. Helsinki: University of Helsinki, Department of Biosciences, Division of Plant Biology. Chap. 2, pp. 35–70. ISBN: ISBN 978-952-10-8363-1 (PDF), 978-952-10-8362-4 (paperback). URL: http://hdl.handle.net/10138/37558.

Aphalo, P. J., T. M. Robson, and H. Högmander (2012). “Statistical design of UV experiments”. In: *Beyond the Visible: A handbook of best practice in plant UV photobiology*. Ed. by P. J. Aphalo, A. Albert, L. O. Björn, A. R. McLeod, T. M. Robson, and E. Rosenqvist. 1st ed. COST Action FA0906 “UV4growth”. Helsinki: University of Helsinki, Department of Biosciences, Division of Plant Biology. Chap. 5, pp. 139–150. ISBN: ISBN 978-952-10-8363-1 (PDF), 978-952-10-8362-4 (paperback). URL: http://hdl.handle.net/10138/37558.

Aphalo, P. J., R. Tegelberg, and R. Julkunen-Tiitto (1999). “The modulated UV-B irradiation system at the University of Joensuu”. In: *Biotronics* 28, pp. 109–120. URL: http://ci.nii.ac.jp/naid/110006175827/en.

Arends, G., R. K. A. M. Mallant, E. van Wensveen, and J. M. Gouman (1988). *A fog chamber for the study of chemical reactions*. Tech. rep. Report - ECN - 210. Petten, Netherlands.

Austin, A. T. and C. L. Ballaré (2010). “Dual role of lignin in plant litter decomposition in terrestrial ecosystems”. In: *Procceedings of the National Academy of Sciences of the U.S.A* 107, pp. 4618–4622. DOI: 10.1073/pnas.0909396107.

Bakker, J. C., G. P. A. Bot, H. Challa, and N. J. Vand de Braak, eds. (1995). *Greenhouse climate control: An integrated approach*. Wageningen, The Netherlands: Wageningen Academic Publishers. 279 pp. ISBN: 978-90-74134-17-0. DOI: 10.3920/978-90-8686-501-7.

Ballaré, C. L., M. M. Caldwell, S. D. Flint, S. A. Robinson, and J. F. Bornman (2011). "Effects of solar ultraviolet radiation on terrestrial ecosystems. Patterns, mechanisms, and interactions with climate change". In: *Photochemical and Photobiological Sciences* 10 (2), pp. 226–241. DOI: 10.1039/C0PP90035D.

Barnes, P. W., S. D. Flint, J. R. Slusser, W. Gao, and R. J. Ryel (2008). "Diurnal changes in epidermal UV transmittance of plants in naturally high UV environments". In: *Physiologia Plantarum* 133, pp. 363–372. DOI: 10.1111/j.1399-3054.2008.01084.x.

Bazzaz, F. A. and R. W. Carlson (1982). "Photosynthetic acclimation to variability in the light environment of early and late successional plants". In: *Oecologia* 54, pp. 313–316. DOI: 10.1007/BF00379999.

Beckerman, A. P. and O. L. Petchey (2012). *Getting Started with R: An introduction for biologists*. Oxford: OUP Oxford, p. 128. ISBN: 0199601623. URL: http://www.amazon.co.uk/Getting-Started-introduction-biologists-Biology/dp/0199601623.

Bentham (1997). *A Guide to Spectroradiometry: Instruments & Applications for the Ultraviolet*. Tech. rep. Reading, U.K.: Bentham Instruments Ltd.

Bérces, A., A. Fekete, S. Gáspár, P. Gróf, P. Rettberg, G. Horneck, and G. Rontó (1999). "Biological UV dosimeters in the assessment of the biological hazard from environmental radiation". In: *Journal of Photochemistry and Photobiology, B* 53.1-3, pp. 36–43. DOI: 10.1016/S1011-1344(99)00123-2.

Berger, D. S. (1976). "The sunburning ultraviolet meter: design and performance". In: *Photochemistry and Photobiology* 24, pp. 587–593. DOI: 10.1111/j.1751-1097.1976.tb06877.x.

Beytes, C., ed. (2003). *Ball Red Book: Greenhouses and equipment*. 17th ed. Batavia, IL, USA: Ball Publishing. 272 pp. ISBN: 1883052343.

Bickford, E. D. and S. Dunn (1972). *Lighting for plant growth*. Ohio, USA: Kent State University Press. x + 221. ISBN: 0873381165.

Bilger, W., T. Johnsen, and U. Schreiber (2001). "UV-excited chlorophyll fluorescence as a tool for the assessment of UV-protection by epidermins of plants". In: *Journal of Experimental Botany* 52, pp. 2007–2014. DOI: 10.1093/jexbot/52.363.2007.

Bilger, W., M. Veit, L. Schreiber, and U. Schreiber (1997). "Measurement of leaf epidermal transmittance of UV radiation by chlorophyll fluorescence". In: *Physiologia Plantarum* 101.4, pp. 754–763. DOI: 10.1111/j.1399-3054.1997.tb01060.x.

Björn, L. O. (1995). "Estimation of fluence rate from irradiance measurements with a cosine-corrected sensor". In: *Journal of Photochemistry and Photobiology B Biology* 29, pp. 179–183. DOI: 10.1016/1011-1344(95)07135-O.

Björn, L. O., ed. (2007). *Photobiology: The Science of Life and Light*. 2nd ed. Springer. 684 pp. ISBN: 0387726543.

Björn, L. O., A. R. McLeod, P. J. Aphalo, A. Albert, A. V. Lindfors, A. Heikkilä, P. Kolarz, L. Ylianttila, G. Zipoli, P. Grifoni D.and Huovinen, et al. (2012). "Quantifying UV radiation". In: *Beyond the Visible: A handbook of best practice in plant UV photobiology*. Ed. by P. J. Aphalo, A. Albert, L. O. Björn, A. R. McLeod, T. M. Robson, and E. Rosenqvist. 1st ed. COST Action FA0906 "UV4growth". Helsinki: University of Helsinki, Department of Biosciences, Division of Plant Biology. Chap. 3, pp. 71–117. ISBN: ISBN 978-952-10-8363-1 (PDF), 978-952-10-8362-4 (paperback). URL: http://hdl.handle.net/10138/37558.

Björn, L. O. and A. H. Teramura (1993). "Simulation of daylight ultraviolet radiation and effects of ozone depletion". In: *Environmental UV Photobiology*. Ed. by A. R. Young, L. O. Björn, J. Moan, and W. Nultsch. New York: Plenum Press, pp. 41–71. ISBN: 0-306-44443-7.

Björn, L. O. and T. C. Vogelmann (1996). "Quantifying light and ultraviolet radiation in plant biology". In: *Photochemistry and Photobiology* 64, pp. 403–406. DOI: 10.1111/j.1751-1097.1996.tb03084.x.

Bloom, A. A., J. Lee-Taylor, S. Madronich, D. J. Messenger, P. I. Palmer, D. S. Reay, and A. R. McLeod (2010). "Global methane emission estimates from ultraviolet irradiation of terrestrial plant foliage". In: *New Phytologist* 187.2, pp. 417–425. DOI: 10.1111/j.1469-8137.2010.03259.x.

Bolker, B. M. (2008). *Ecological Models and Data in R*. 508th ed. Princeton University Press. ISBN: 0691125228.

Booker, F. L., E. L. Fiscus, R. B. Philbeck, A. S. Heagle, J. E. Miller, and W. W. Heck (1992). "A supplemental ultraviolet-B radiation system for open-top chambers". In: *Journal of Environmental Quality* 21, pp. 56–61.

Borcard, D., F. Gillet, and P. Legendre (2011). *Numerical Ecology with R*. Springer, p. 312. ISBN: 1441979751. URL: http://www.amazon.com/Numerical-Ecology-R-Use/dp/1441979751.

Bornman, J. F. and T. C. Vogelmann (1988). "Penetration by blue and UV radiation measured by fiber optics in spruce and fir needles". In: *Physiologia Plantarum* 72.4, pp. 699–705. DOI: 10.1111/j.1399-3054.1988.tb06368.x.

Bowman, W. D. and J. N. Demas (1976). "Ferrioxalate actinometry - Warning on its correct use". In: *Journal of Physical Chemistry* 80.21, pp. 2434–2435. ISSN: 0022-3654. DOI: 10.1021/j100562a025.

Braslavsky, S. E. (2007). "Glossary of terms used in Photochemistry 3(rd) Edition (IUPAC Recommendations 2006)". In: *Pure and Applied Chemistry* 79.3, pp. 293–465. DOI: 10.1351/pac200779030293.

Bricaud, A., M. Babin, A. Morel, and H. Claustre (1995). "Variability in the chlorophyll-specific absorption coefficients of natural phytoplankton: analysis and parameterization". In: *Journal of Geophysical Research* 100.C7, pp. 13321–13332.

Bricaud, A., A. Morel, and L. Prieur (1981). "Absorption by dissolved organic matter of the sea (yellow substance) in the UV and visible domains". In: *Limnology and Oceanography* 26.1, pp. 43–53. URL: http://www.jstor.org/stable/2835805.

Brooms, A. C. (2010). *Data Manipulation with R*. DOI: 10.1080/02664760903075531.

Brown, M. J., G. G. Parker, and N. E. Posner (1994). "A survey of ultraviolet-B radiation in forests". In: *Journal of Ecology* 82.4, pp. 843–854. URL: http://www.jstor.org/stable/2261448.

Buiteveld, H., J. H. M. Hakvoort, and M. Donze (1994). "The optical properties of pure water". In: *Proceedings of SPIE "Ocean Optics XII"*. Vol. 2258. International Society for Optical Engineering, pp. 174–183.

Caldwell, M. M. (1971). "Solar UV irradiation and the growth and development of higher plants". In: *Photophysiology*. Ed. by A. C. Giese. Vol. 6. New York: Academic Press, pp. 131–177. ISBN: 012282606X (cit. on p. xv).

Caldwell, M. M. and S. D. Flint (1994a). "Lighting considerations in controlled environments for nonphotosynthetic plant responses to blue and ultraviolet radiation". In: *Proceedings of the International Lighting in Controlled Environments Workshop*. Vol. NASA-CP-95-3309, pp. 113–124.

– (1994b). "Stratospheric ozone reduction, solar UV-B radiation and terrestrial ecosystems". In: *Climatic Change* 28.4, pp. 375–394. DOI: 10.1007/BF01104080.

Caldwell, M. M. and S. D. Flint (2006). "Use and Evaluation of Biological Spectral UV Weighting Functions for the Ozone Reduction Issue". In: *Environmental UV Radiation: Impact on Ecosystems and Human Health and Predictive Models*. Ed. by F. Ghetti, G. Checcucci, and J. F. Bornman. Vol. 57. NATO Science Series. Proceedings of the NATO Advanced Study Institute on Environmental UV Radiation: Impact on Ecosystems and Human Health and Predictive Models Pisa, Italy June 2001. Dordrecht: Springer, pp. 71–84. ISBN: 978-1-4020-3695-8. DOI: 10.1007/1-4020-3697-3.

Caldwell, M. M., S. D. Flint, and P. S. Searles (1994). "Spectral balance and UV-B sensitivity of soybean: A field experiment". In: *Plant, Cell and Environment* 17.3, pp. 267–276. DOI: 10.1111/j.1365-3040.1994.tb00292.x.

Caldwell, M. M., W. G. Gold, G. Harris, and C. W. Ashurst (1983). "A modulated lamp system for solar UV-B (280-320 nm) supplementation studies in the field". In: *Photochemistry and Photobiology* 37, pp. 479–485. DOI: 10.1111/j.1751-1097.1983.tb04503.x.

Caldwell, M. M., A. H. Teramura, and M. Tevini (1989). "The Changing Solar Ultraviolet Climate and the Ecological Consequences for Higher Plants". In: *Trends in Ecology & Evolution* 4.12, pp. 363–367. DOI: 10.1016/0169-5347(89)90100-6.

Campbell, G. S. and J. M. Norman (1998). *An Introduction to Environmental Biophysics*. 2nd ed. New York: Springer. 286 pp. ISBN: 0-387-94937-2.

Cen, Y.-P. and J. F. Bornman (1993). "The effect of exposure to enhanced UV-B radiation on the penetration of monochromatic and polychromatic UV-B radiation in leaves of Brassica napus". In: *Physiologia Plantarum* 87.3, pp. 249–255. DOI: 10.1111/j.1399-3054.1993.tb01727.x.

Chambers, J. (2009). *Software for Data Analysis: Programming with R (Statistics and Computing)*. Springer, p. 498. ISBN: 0387759352. URL: http://www.amazon.com/Software-Data-Analysis-Programming-Statistics/dp/0387759352.

Chang, W. (2013). *R Graphics Cookbook*. 1-2. Sebastopol: O'Reilly Media, p. 413. ISBN: 9781449316952. URL: http://medcontent.metapress.com/index/A65RM03P4874243N.pdf.

Christie, J. M. (2007). "Phototropin Blue-Light Receptors". In: *Annual Review of Plant Biology* 58, pp. 21–45. DOI: 10.1146/annurev.arplant.58.032806.103951.

Christie, J. M., A. S. Arvai, K. J. Baxter, M. Heilmann, A. J. Pratt, A. O'Hara, S. M. Kelly, M. Hothorn, B. O. Smith, K. Hitomi, et al. (2012). "Plant UVR8 Photoreceptor Senses UV-B by Tryptophan-Mediated Disruption of Cross-Dimer Salt Bridges". In: *Science*. DOI: 10.1126/science.1218091.

Cochran, W. G. (1957). "Analysis of covariance its nature and uses". In: *Biometrics* 13, pp. 261–281. URL: http://www.jstor.org/stable/2527916.

Cohen, J. (1977). *Statistical Power Analysis for the Behavioral Sciences*. Revised edition. New York: Academic Press. 474 pp.

Coleman, A., R. Sarkany, and S. Walker (2008). "Clinical ultraviolet dosimetry with a CCD monochromator array spectroradiometer". In: *Physics in Medicine and Biology* 53.18, pp. 5239–5255. DOI: 10.1088/0031-9155/53/18/026.

Coohill, T. P. (1992). "Action spectroscopy and stratospheric ozone depletion". In: *UV-B monitoring workshop: a review of the science and status of measuring and monitoring programs*. Science and Policy Associaties, Washington D.C., pp. C89–C112.

Cooley, N. M., H. M. F. Truscott, M. G. Holmes, and T. H. Attridge (2000). "Outdoor ultraviolet polychromatic action spectra for growth responses of *Bellis perennis* and *Cynosurus cristatus*". In: *Journal of Photochemistry and Photobiology B: Biology* 59.1-3, pp. 64–71. DOI: 10.1016/S1011-1344(00)00141-X.

Cox, D. R. (1958). *Planning of Experiments*. New York: John Wiley & Sons. 308 pp.

Cox, D. R. and N. Reid (2000). *The Theory of the Design of Experiments*. 1st ed. Chapman and Hall/CRC. 314 pp. ISBN: 158488195X.

Crawley, M. J. (2002). *Statistical Computing: An Introduction to Data Analysis using {S}-Plus*. Chichester: Wiley, pp. x + 761. ISBN: 0-471-56040-5. URL: http://www.amazon.com/dp/0471560405.

– (2005). *Statistics: An Introduction using R*. Wiley, p. 342. ISBN: 0470022981. URL: http://www.amazon.com/Statistics-An-Introduction-using-R/dp/0470022981%20http://www.amazon.com/dp/0470022981.

– (2007). *The R Book*. John Wiley and Sons Ltd, p. 950. ISBN: 0470510242. URL: http://www.amazon.co.uk/dp/0470510242%20http://www.amazon.com/The-Book-Michael-J-Crawley/dp/0470973927%20http://www.amazon.com/The-Book-Michael-J-Crawley/dp/0470510242.

– (2012). *The R Book*. Wiley, p. 1076. ISBN: 0470973927. URL: http://www.amazon.com/The-Book-Michael-J-Crawley/dp/0470973927.

Cryer, J. D. and K.-S. Chan (2009). *Time Series Analysis: With Applications in R (Springer Texts in Statistics)*. Springer, p. 508. ISBN: 0387759581. URL: http://www.amazon.co.uk/Time-Series-Analysis-Applications-Statistics/dp/0387759581.

Cullen, J. J. and P. J. Neale (1997). "Biological weighting functions for describing the effects of ultraviolet radiation on aquatic systems". In: *The effects of ozone depletion on aquatic ecosystems*. Ed. by D.-P. Häder. Academic Press. Chap. 6, pp. 97–118. ISBN: 0123991730.

Dalgaard, P. (2002). *Introductory Statistics with R*. Statistics and Computing. New York: Springer, pp. xv + 267. ISBN: 0 387 95475 9.

Dalgaard, P. (2008). *Introductory Statistics with R*. Springer, p. 380. ISBN: 0387790543.

D'Antoni, H. L., L. J. Rothschild, C. Schultz, S. Burgess, and J. W. Skiles (2007). "Extreme environments in the forests of Ushuaia, Argentina". In: *Geophysical Research Letters* 34.22. ISSN: 0094-8276. DOI: 10.1029/2007GL031096.

D'Antoni, H. L., L. J. Rothschild, and J. W. Skiles (2008). "Reply to comment by Stephan D. Flint et al. on "Extreme environments in the forests of Ushuaia, Argentina"". In: *Geophysical Research Letters* 35.13. ISSN: 0094-8276. DOI: 10.1029/2008GL033836.

de la Rosa, T. M., R. Julkunen-Tiitto, T. Lehto, and P. J. Aphalo (2001). "Secondary metabolites and nutrient concentrations in silver birch seedlings under five levels of daily UV-B exposure and two relative nutrient addition rates". In: *New Phytologist* 150, pp. 121–131. DOI: 10.1046/j.1469-8137.2001.00079.x.

Deckmyn, G., E. Cayenberghs, and R. Ceulemans (2001). "UV-B and PAR in single and mixed canopies grown under different UV-B exclusions in the field". In: *Plant Ecology* 154, pp. 125–133. DOI: 10.1023/A:1012920716047.

Dekker, A. G. (1993). "Detection of optical water quality parameters for eutrophic waters by high resolution remote sensing". PhD thesis. Vrije Universiteit Amsterdam.

DeLucia, E. H., T. A. Day, and T. C. Vogelman (1992). "Ultraviolet-B and visible light penetration into needles of two species of subalpine conifers during foliar development". In: *Plant, Cell and Environment* 15.8, pp. 921–929. DOI: 10.1111/j.1365-3040.1992.tb01024.x.

Demas, J. N., W. D. Bowman, E. F. Zalewski, and R. A. Velapoldi (1981). "Determination of the quantum yield of the ferrioxalate actinometer with electrically calibrated radiometers". In: *Journal of Physical Chemistry* 85.19, pp. 2766–2771. ISSN: 0022-3654. DOI: 10.1021/j150619a015.

Díaz, S., C. Camilión, J. Escobar, G. Deferrari, S. Roy, K. Lacoste, S. Demers, C. Belzile, G. Ferreyra, S. Gianesella, et al. (2006). "Simulation of ozone depletion using ambient irradiance supplemented with UV lamps." In: *Photochemistry and Photobiology* 82.4, pp. 857–864. DOI: 10.1562/2005-09-28-RA-700.

Díaz, S. B., J. E. Frederick, T. Lucas, C. R. Booth, and I. Smolskaia (1996). "Solar ultraviolet irradiance at Tierra del Fuego: Comparison of measurements and calculations over a full annual cycle". In: *Geophysical Research Letters* 23.4, pp. 355–358. DOI: 10.1029/96GL00253.

Diffey, B. L. (1987). "A comparison of dosimeters used for solar ultraviolet radiometry". In: *Photochem Photobiol* 46, pp. 55–60. DOI: 10.1111/j.1751-1097.1987.tb04735.x.

– (1989). *Radiation Measurement in Photobiology*. London: Academic Press. 230 pp. ISBN: 0122158407.

Dixon, J. M., M. Taniguchi, and J. S. Lindsey (2005). "PhotochemCAD 2: a refined program with accompanying spectral data bases for photochemical calculations". In: *Photochemistry and Photobiology* 81.1, pp. 212–213. DOI: 10.1111/j.1751-1097.2005.tb01544.x.

Döhring, T., M. Köfferlein, S. Thiel, and H. K. Seidlitz (1996). "Spectral shaping of artificial UV-B irradiation for vegetation stress research". In: *Journal of Plant Physiology* 148, pp. 115–119. DOI: 10.1016/S0176-1617(96)80302-6.

Du, H., R.-. C. A. Fuh, J. Li, L. A. Corkan, and J. S. Lindsey (1998). "PhotochemCAD: a computer-aided design and research tool in photochemistry". In: *Photochemistry and Photobiology* 68.2, pp. 141–142. DOI: 10.1111/j.1751-1097.1998.tb02480.x.

Dunne, R. P. (1999). "Polysulphone film as an underwater dosimeter for solar ultraviolet-B radiation in tropical latitudes". In: *Marine Ecology Progress Series* 189, pp. 53–63. DOI: 10.3354/meps189053.

Eddelbuettel, D. (2013). *Seamless R and C++ Integration with Rcpp*. Springer, p. 248. ISBN: 1461468671. URL: http://www.amazon.co.uk/Seamless-Integration-Rcpp-Dirk-Eddelbuettel/dp/1461468671.

Eichler, H.-. J., A. Fleischner, J. Kross, M. Krystek, H. Lang, H. Niedrig, H. Rauch, G. Schmahl, H. Schoenebeck, E. Sedlmayr, et al. (1993). *Bergmann, Schaefer: Lehrbuch der Experimentalphysik Band 3: Optik*. Ed. by H. Niedrig. Verlag Walter de Gruyter Berlin/New York.

Einstein, A. (1910). "Theorie der Opaleszenz von homogenen Flüssigkeiten und Flüssigkeitsgemischen in der Nähe des kritischen Zustandes". In: *Annalen der Physik IV. Folge* 33.16, pp. 1275–1298.

Eisinger, W., T. E. Swartz, R. A. Bogomolni, and L. Taiz (2000). "The ultraviolet action spectrum for stomatal opening in broad bean". In: *Plant Physiology* 122, pp. 99–105. DOI: http://dx.doi.org/10.1104/pp.122.1.99.

Everitt, B. and T. Hothorn (2011). *An Introduction to Applied Multivariate Analysis with R*. Springer, p. 288. ISBN: 1441996494. URL: http://www.amazon.co.uk/Introduction-Applied-Multivariate-Analysis-Use/dp/1441996494.

Everitt, B. S. and T. Hothorn (2009). *A Handbook of Statistical Analyses Using R*. 2nd ed. Chapman & Hall, p. 376. ISBN: 1420079336. URL: http://www.amazon.com/Handbook-Statistical-Analyses-Second-Edition/dp/1420079336.

Faraway, J. J. (2004). *Linear Models with R*. Boca Raton, FL: Chapman & Hall/CRC, p. 240. URL: http://www.maths.bath.ac.uk/~jjf23/LMR/.

Faraway, J. J. (2006). *Extending the linear model with R: generalized linear, mixed effects and nonparametric regression models*. Chapman & Hall/CRC Taylor & Francis Group, p. 345. ISBN: 158488424X.

Fernández, E., J. M. Figuera, and A. Tobar (1979). "Use of the potassium ferrioxalate actinometer below 254-nm". In: *Journal of Photochemistry* 11.1, pp. 69–71. ISSN: 0047-2670. DOI: 10.1016/0047-2670(79)85008-X.

Flenley, J. R. (1992). "Ultraviolet-B insolation and the altitudinal forest limit". In: *Nature and dynamics of forest savanna boundaries*. Ed. by P. A. Furley, J. Proctor, and J. A. Ratter. London: Chapman & Hall, pp. 273–282.

Flint, S. D., C. L. Ballare, M. M. Caldwell, and R. L. McKenzie (2008). "Comment on "Extreme environments in the forests of Ushuaia, Argentina" by Hector D'Antoni et al." In: *Geophysical Research Letters* 35.13. ISSN: 0094-8276. DOI: 10.1029/2008GL033570.

Flint, S. D. and M. M. Caldwell (1996). "Scaling plant ultraviolet spectral responses from laboratory action spectra to field spectral weighting factors". In: *Journal of Plant Physiology* 148, pp. 107–114. DOI: 10.1016/S0176-1617(96)80301-4.

Flint, S. D. and M. M. Caldwell (1998). "Solar UV-B and visible radiation in tropical forest gaps: measurements partitioning direct and diffuse radiation". In: *Global Change Biology* 4.8, pp. 863–870. DOI: 10.1046/j.1365-2486.1998.00191.x.

Flint, S. D. and M. M. Caldwell (2003). "A biological spectral weighting function for ozone depletion research with higher plants". In: *Physiologia Plantarum* 117, pp. 137–144. DOI: 10.1034/j.1399-3054.2003.1170117.x.

Flint, S. D., R. J. Ryel, T. J. Hudelson, and M. M. Caldwell (2009). "Serious complications in experiments in which UV doses are effected by using different lamp heights". In: *Journal of Photochemistry and Photobiology, B* 97.1, pp. 48–53. DOI: 10.1016/j.jphotobiol.2009.07.010.

Fox, J. (2002). *An {R} and {S-Plus} Companion to Applied Regression*. Thousand Oaks, CA, USA: Sage Publications. URL: http://socserv.socsci.mcmaster.ca/jfox/Books/Companion/index.html.

Fox, J. and H. S. Weisberg (2010). *An R Companion to Applied Regression*. SAGE Publications, Inc, p. 472. ISBN: 141297514X. URL: http://www.amazon.com/An-R-Companion-Applied-Regression/dp/141297514X.

Frederick, J. E., P. F. Soulen, S. B. Diaz, I. Smolskaia, C. R. Booth, T. Lucas, and D. Neuschuler (1993). "Solar Ultraviolet Irradiance Observed From Southern Argentina: September 1990

to March 1991". In: *Journal of Geophysical Research* 98, pp. 8891–8897. DOI: 10.1029/93JD00030.

Frigaard, N.-. U., K. L. Larsen, and R. P. Cox (1996). "Spectrochromatography of photosynthetic pigments as a fingerprinting technique for microbial phototrophs". In: *FEMS Microbiology Ecology* 20, pp. 69–77. DOI: 10.1111/j.1574-6941.1996.tb00306.x.

Fröhlich, C. and J. Lean (2004). "Solar radiative output and its variability: evidence and mechanisms". In: *The Astronomy and Astrophysics Review* 12, pp. 273–320. DOI: 10.1007/s00159-004-0024-1.

Furness, N. H., P. A. Jolliffe, and M. K. Upadhyaya (2005). "Ultraviolet-B Radiation and Plant Competition: Experimental Approaches and Underlying Mechanisms". In: *Photochemistry and Photobiology* 81, pp. 1026–1037. DOI: 10.1562/2005-08-18-RA-482.

Furusawa, Y., L. E. Quintern, H. Holtschmidt, P. Koepke, and M. Saito (1998). "Determination of erythema-effective solar radiation in Japan and Germany with a spore monolayer film optimized for the detection of UVB and UVA–results of a field campaign". In: *Appl Microbiol Biotechnol* 50, pp. 597–603. DOI: 10.1007/s002530051341.

Gandrud, C. (2013). *Reproducible Research with R and RStudio*. Chapman and Hall/CRC, p. 294. ISBN: 1466572841. URL: http://www.amazon.com/Reproducible-Research-RStudio-Chapman-Series/dp/1466572841.

García-Pichel, F. (1995). "A scalar irradiance fiber-optic microprobe for the measurement of ultraviolet radiation at high spatial resolution". In: *Photochemistry and Photobiology* 61, pp. 248–254. DOI: 10.1111/j.1751-1097.1995.tb03967.x.

Gege, P. (1998). "Characterization of the phytoplankton in Lake Constance for classification by remote sensing". In: *Archiv für Hydrobiologie, Special issues: Advances in Limnology* 53, pp. 179–193.

– (2004). "The water color simulator WASI: an integrating software tool for analysis and simulation of optical in situ spectra". In: *Computers and Geosciences* 30, pp. 523–532. DOI: 10.1016/j.cageo.2004.03.005.

Geiss, O. (2003). *Manual for polysulphone dosimeter*. Tech. rep. EUR 20981 EN. European Union. URL: http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/1227/1/EUR%2020981%20EN.pdf.

Gentleman, R. (2008). *R Programming for Bioinformatics*. Chapman and Hall/CRC, p. 328. ISBN: 1420063677. URL: http://www.amazon.com/Programming-Bioinformatics-Chapman-Computer-Analysis/dp/1420063677.

Ghetti, F., H. Herrmann, D.-. P. Häder, and H. K. Seidlitz (1999). "Spectral dependence of the inhibition of photosynthesis under simulated global radiation in the unicellular green alga *Dunaliella salina*". In: *Journal of Photochemistry and Photobiology B: Biology* 48, pp. 166–173. DOI: 10.1016/S1011-1344(99)00043-3.

Goldstein, S. and J. Rabani (2008). "The ferrioxalate and iodide-iodate actinometers in the UV region". In: *Journal of Photochemistry and Photobiology A-Chemistry* 193.1, pp. 50–55. ISSN: 1010-6030. DOI: 10.1016/j.jphotochem.2007.06.006.

Gordon, H. R. and A. Y. Morel (1983). *Remote assessment of ocean color for interpretation of satellite visible imagery: a review*. Ed. by R. T. Barber, C. N. K. Mooers, M. J. Bowman, and B. Zeitzschel. Vol. 4. Lecture Notes on Coastal and Estuarine Studies. New York: Springer Verlag.

Gorton, H. L. (2010). "Biological action spectra". In: *Photobiological Sciences Online*. Ed. by K. C. Smith. American Society for Photobiology. URL: http://www.photobiology.info/Gorton.html.

Götz, M., A. Albert, S. Stich, W. Heller, H. Scherb, A. Krins, C. Langebartels, H. K. Seidlitz, and D. Ernst (2010). "PAR modulation of the UV-dependent levels of flavonoid metabolites in *Arabidopsis thaliana* (L.) Heynh. leaf rosettes: cumulative effects after a whole vegetative growth period". In: *Protoplasma* 243, pp. 95–103. DOI: 10.1007/s00709-009-0064-5.

Goulas, Y., Z. G. Cerovic, A. Cartelat, and I. Moya (2004). "Dualex: a new instrument for field measurements of epidermal ultraviolet absorbance by chlorophyll fluorescence". In: *Applied Optics* 43.23, pp. 4488–4496. DOI: 10.1364/AO.43.004488.

Gould, K. S., T. C. Vogelmann, T. Han, and M. J. Clearwater (2002). "Profiles of photosynthesis within red and green leaves of *Quintinia serrata*". In: *Physiologia Plantarum* 116.1, pp. 127–133. DOI: 10.1034/j.1399-3054.2002.1160116.x.

Graedel, T. E. and P. J. Crutzen (1993). *Atmospheric Change: An Earth System Perspective*. New York: WH Freeman. 446 pp. ISBN: board 0-7167-2334-4, paper 0-7167-2332-8.

Grant, R. H. (1998). "Ultraviolet irradiance of inclined planes at the top of plant canopies". In: *Agricultural and Forest Meteorology* 89, pp. 281–293. DOI: 10.1016/S0168-1923(97)00067-1.

– (1999a). "Potential effect of soybean heliotropism on ultraviolet-B irradiance and dose". In: *Agronomy Journal* 91, pp. 1017–1023. DOI: doi:10.2134/agronj1999.9161017x.

– (1999b). "Ultraviolet-B and photosynthetically active radiation environment of inclined leaf surfaces in a maize canopy and implications for modeling". In: *Agricultural and Forest Meteorology* 95, pp. 187–201. DOI: 10.1016/S0168-1923(99)00023-4.

– (2004). "UV Radiation Penetration in Plant Canopies". In: *Encyclopedia of Plant and Crop Science*, pp. 1261–1264. DOI: 10.1081/E-EPCS-120010624.

Green, A. E. S. and J. H. Miller (1975). "Measures of biologically active radiation in the 280-340 nm region. Impacts of climate change on the environment". In: CIAP Monograph 5, Part 1. Chap. 2.2.4.

Green, A. E. S., T. Sawada, and E. P. Shettle (1974). "The middle ultraviolet reaching the ground". In: *Photochemistry and Photobiology* 19, pp. 251–259. DOI: 10.1111/j.1751-1097.1974.tb06508.x (cit. on p. xv).

Grifoni, D., F. Sabatini, G. Zipoli, and M. Viti (2009). "Action spectra affect variability in the climatology of biologically effective UV radiation (UVBE)". In: *Poster presentation at the Final Seminar of COST Action 726, 13-14 May 2009, Warsaw, Poland*.

Grifoni, D., G. Zipoli, M. Viti, and F. Sabatini (2008). "Latitudinal and seasonal distribution of biologically effective UV radiation affecting human health and plant growth". In: *Proceedings of 18th International Congress of Biometeorology, 22-26 September 2008, Tokyo, Japan*.

Häder, D.-P., E. W. Helbling, C. E. Williamson, and R. C. Worrest (2011). "Effects of UV radiation on aquatic ecosystems and interactions with climate change". In: *Photochemical and Photobiological Sciences* 10 (2), pp. 242–260. DOI: 10.1039/C0PP90036B.

Häder, D.-P., M. Lebert, M. Schuster, L. del Ciampo, E. W. Helbling, and R. McKenzie (2007). "ELDONET—a decade of monitoring solar radiation on five continents". In: *Photochem Photobiol* 83, pp. 1348–1357. DOI: 10.1111/j.1751-1097.2007.00168.x.

Hahne, F., W. Huber, R. Gentleman, and S. Falcon (2008). *Bioconductor Case Studies (Use R!)* Springer, p. 284. ISBN: 0387772391. URL: http://www.amazon.com/Bioconductor-Case-Studies-Use-R/dp/0387772391.

Hakvoort, J. H. M. (1994). "Absorption of light by surface water". PhD thesis. Delft University of Technology.

Hannay, J. W. and D. J. Millar (1986). "Phytotoxicity of phthalate plasticisers. I. Diagnosis and commercial implications". In: *Journal of Experimental Botany* 37, pp. 883–897. DOI: 10.1093/jxb/37.6.883.

Hardwick, R. C. and R. A. Cole (1987). "Plastics that kill plants". In: *Outlook on Agriculture* 16.13, pp. 100–104.

Hatchard, C. G. and C. A. Parker (1956). "A new sensitive chemical actinometer .2. Potassium ferrioxalate as a standard chemical actinometer". In: *Proceedings of the Royal Society of London Series A-Mathematical and Physical Sciences* 235.1203, pp. 518–536. DOI: 10.1098/rspa.1956.0102.

Hegglin, M. I. and T. G. Shepherd (2009). "Large climate-induced changes in ultraviolet index and stratosphere-to-troposphere ozone flux". In: *Nature Geoscience* advance online publication, pp. 687–691. DOI: 10.1038/ngeo604.

Heijde, M. and R. Ulm (2012). "UV-B photoreceptor-mediated signalling in plants". In: *Trends in Plant Science*. DOI: 10.1016/j.tplants.2012.01.007.

Hirose, T. (2005). "Development of the Monsi–Saeki Theory on Canopy Structure and Function". In: *Annals of Botany* 95, pp. 483–494. DOI: 10.1093/aob/mci047.

Hogewoning, S. W., P. Douwstra, G. Trouwborst, W. van Ieperen, and J. Harbinson (2010). "An artificial solar spectrum substantially alters plant development compared with usual climate room irradiance spectra". In: *Journal of Experimental Botany* 61.5, pp. 1267–1276. DOI: 10.1093/jxb/erq005.

Holmes, M. G. (1984). "Light Sources". In: *Techniques in Photomorphogenesis*. Ed. by H. Smith and M. G. Holmes. Academic press, pp. 43–79. ISBN: 0126529906.

– (1997). "Action spectra for UV-B effects on plants: monochromatic and polychromatic approaches for analysing plant responses". In: *Plants and UV-B - responses to environmental change*. Ed. by P. J. Lumsden. Cambridge University Press, pp. 31–50. ISBN: 0521572223.

Holmes, M. G. and D. R. Keiller (2002). "Effects of pubescence and waxes on the reflectance of leaves in the ultraviolet and photosynthetic wavebands: a comparison of a range of species". In: *Plant Cell and Environment* 25.1, pp. 85–93. DOI: 10.1046/j.1365-3040.2002.00779.x.

Horneck, G., P. Rettberg, E. Rabbow, W. Strauch, G. Seckmeyer, R. Facius, G. Reitz, K. Strauch, and J. U. Schott (1996). "Biological dosimetry of solar radiation for different simulated ozone column thicknesses". In: *Journal of Photochemistry and Photobiology B-biology* 32.3, pp. 189–196. ISSN: 1011-1344. DOI: 10.1016/1011-1344(95)07219-5.

Hulst, H. C. van de (1981). *Light scattering by small particles*. unabridged and corrected republication of the work originally published in 1957 by John Wiley & Sons Inc. New York. New York: Dover Publications Inc.

Hunt, J. E. (1997). "Ultraviolet-B radiation and its effects on New Zealand trees". Ph.D. Dissertation. Canterbury, New Zealand: Lincoln University, p. 106.

Hunt, J. E. and D. L. McNeil (1998). "Nitrogen status affects UV-B sensitivity of cucumber". In: *Australian Journal of Plant Physiology* 25.1, pp. 79–86. DOI: 10.1071/PP97102.

Hurlbert, S. H. (1984). "Pseudoreplication and the design of ecological field experiments". In: *Ecological Monographs* 54.2, pp. 187–211. DOI: 10.2307/1942661.

Hyndman, R., A. B. Koehler, J. K. Ord, and R. D. Snyder (2008). *Forecasting with Exponential Smoothing: The State Space Approach*. Springer, p. 362. ISBN: 3540719164. URL: http://www.amazon.co.uk/Forecasting-Exponential-Smoothing-Approach-Statistics/dp/3540719164.

Ibdah, M., A. Krins, H. K. Seidlitz, W. Heller, D. Strack, and T. Vogt (2002a). "Spectral dependence of flavonol and betacyanin accumulation in *Mesembryanthemum crystallinum* under enhanced ultraviolet radiation". In: *Plant, Cell and Environment* 25.9, pp. 1145–1154. DOI: doi:10.1046/j.1365-3040.2002.00895.x.

– (2002b). "Spectral dependence of flavonol and betacyanin accumulation in Mesembryanthemum crystallinum under enhanced ultraviolet radiation". In: *Plant, Cell and Environment* 25, pp. 1145–1154. DOI: 10.1046/j.1365-3040.2002.00895.x.

Ihaka, R. and R. Gentleman (1996). "R: A Language for Data Analysis and Graphics". In: *J. Comput. Graph. Stat.* 5, pp. 299–314.

Iqbal, M. (1983). *An introduction to solar radiation*. Academic Press Canada.

Jagger, J. (1967). *Introduction to research in ultraviolet photobiology*. Englewood Cliffs, NJ, USA: Prentice-Hall. 164 pp. ISBN: 0134955722.

Jansen, M. A. K. and J. F. Bornman (2012). "UV-B radiation: from generic stressor to specific regulator". In: *Physiologia Plantarum* 145.4, pp. 501–504. ISSN: 1399-3054. DOI: 10.1111/j.1399-3054.2012.01656.x.

Jenkins, G. I. (2009). "Signal transduction in responses to UV-B radiation". In: *Annual Review of Plant Biology* 60, pp. 407–431. DOI: 10.1146/annurev.arplant.59.032607.092953.

Jones, H. G. (1992). *Plants and Microclimate: A Quantitative Approach to Environmental Plant Physiology*. 2nd ed. Cambridge University Press. 456 pp. ISBN: 0521425247.

Jones, L. W. and B. Kok (1966). "Photoinhibition of Chloroplast Reactions. II. Multiple Effects". In: *Plant Physiology* 41, pp. 1044–1049. DOI: 10.1104/pp.41.6.1044.

Julkunen-Tiitto, R., H. Häggman, P. J. Aphalo, A. Lavola, R. Tegelberg, and T. Veteli (2005). "Growth and defense in deciduous trees and shrubs under UV-B". In: *Environmental Pollution* 137, pp. 404–414. DOI: 10.1016/j.envpol.2005.01.050.

Kalbin, G., S. Li, H. Olsman, M. Pettersson, M. Engwall, and Å. Strid (2005). "Effects of UV-B in biological and chemical systems: equipment for wavelength dependence determination". In: *Journal of Biochemical and Biophysical Methods* 65, pp. 1–12. DOI: 10.1016/j.jbbm.2005.09.001.

Kalbina, I., S. Li, G. Kalbin, L. Björn, and Å. Strid (2008). "Two separate UV-B radiation wavelength regions control expression of different molecular markers in *Arabidopsis thaliana*". In: *Functional Plant Biology* 35.3, pp. 222–227. DOI: 10.1071/FP07197.

Kalle, K. (1966). "The problem of the gelbstoff in the sea". In: *Oceanography and Marine Biology Annual Review* 4, pp. 91–104.

Karabourniotis, G. and J. F. Bornman (1999). "Penetration of UV-A, UV-B and blue light through the leaf trichome layers of two xeromorphic plants, olive and oak, measured by optical fibre microprobes". In: *Physiologia Plantarum* 105, pp. 655–661. DOI: 10.1034/j.1399-3054.1999.105409.x.

Keen, K. J. (2010). *Graphics for Statistics and Data Analysis with R*. Chapman and Hall/CRC, p. 489. ISBN: 1584880872. URL: http://www.amazon.com/Graphics-Statistics-Analysis-Chapman-Statistical/dp/1584880872.

Keiller, D. R., S. A. H. Mackerness, and M. G. Holmes (2003). "The action of a range of supplementary ultraviolet (UV) wavelengths on photosynthesis in Brassica napus L. in the natural environment: effects on PSII, CO2 assimilation and level of chloroplast proteins". In: *Photosynthesis Research* 75.2, pp. 139–150. DOI: 10.1023/A:1022812229445.

Kirk, A. D. and C. Namasivayam (1983). "Errors in ferrioxalate actinometry". In: *Analytical Chemistry* 55.14, pp. 2428–2429. ISSN: 0003-2700. DOI: 10.1021/ac00264a053.

Kirk, J. T. O. (1991). "Volume scattering function, average cosine, and the underwater light field". In: *Limnology and Oceanography* 36.3, pp. 455–467. URL: http://www.jstor.org/stable/2837511.

Kolb, C. A., U. Schreiber, R. Gademann, and E. E. Pfündel (2005). "UV-A screening in plants determined using a new portable fluorimeter". In: *Photosynthetica* 43.3, pp. 371–377. DOI: 10.1007/s11099-005-0061-7.

Kopp, G. and J. L. Lean (2011). "A new, lower value of total solar irradiance: Evidence and climate significance". In: *Geophys. Res. Lett.* 38.1, pp. L01706–. DOI: 10.1029/2010GL045777.

Kotilainen, T., A. Lindfors, R. Tegelberg, and P. J. Aphalo (2011). "How realistically does outdoor UV-B supplementation with lamps reflect ozone depletion: An assessment of enhancement errors". In: *Photochemistry and Photobiology* 87, pp. 174–183. DOI: 10.1111/j.1751-1097.2010.00843.x.

Kotilainen, T., R. Tegelberg, R. Julkunen-Tiitto, A. Lindfors, and P. J. Aphalo (2008). "Metabolite specific effects of solar UV-A and UV-B on alder and birch leaf phenolics". In: *Global Change Biology* 14, pp. 1294–1304. DOI: 10.1111/j.1365-2486.2008.01569.x.

Kotilainen, T., T. Venäläinen, R. Tegelberg, A. Lindfors, R. Julkunen-Tiitto, S. Sutinen, R. B. O'Hara, and P. J. Aphalo (2009). "Assessment of UV Biological Spectral Weighting Functions for Phenolic Metabolites and Growth Responses in Silver Birch Seedlings". In: *Photochemistry and Photobiology* 85, pp. 1346–1355. DOI: 10.1111/j.1751-1097.2009.00597.x.

Kowalczuk, P., M. Zabłocka, S. Sagan, and K. Kuliński (2010). "Fluorescence measured in situ as a proxy of CDOM absorption and DOC concentration in the Baltic Sea". In: *Oceanologia* 52.3, pp. 431–471.

Kreuter, A. and M. Blumthaler (2009). "Stray light correction for solar measurements using array spectrometers". In: *Review of Scientific Instruments* 80.9, 096108, p. 096108. DOI: 10.1063/1.3233897.

Krizek, D. T. and R. M. Mirecki (2004). "Evidence for phytotoxic effects of cellulose acetate in UV exclusion studies". In: *Environmental and Experimental Botany* 51, pp. 33–43. DOI: 10.1016/S0098-8472(03)00058-3.

Kuhn, H., S. Braslavsky, and R. Schmidt (2004). "Chemical actinometry". In: *Pure and Applied Chemistry* 76.12, pp. 2105–2146. ISSN: 0033-4545. DOI: 10.1351/pac200476122105.

Kuhn, H. J., S. E. Braslavsky, and R. Schmidt (1989). "Chemical actinometry". In: *Pure and Applied Chemistry* 61.2, pp. 187–210. ISSN: 0033-4545. DOI: 10.1351/pac198961020187.

Langhans, R. W. and T. W. Tibbitts, eds. (1997). *Plant growth chamber handbook*. Vol. SR-99. North Central Regional Research Publication 340. Iowa Agriculture and Home Economics Experiment Station. URL: http://www.controlledenvironments.org/Growth_Chamber_Handbook/Plant_Growth_Chamber_Handbook.htm.

Lee, J. and H. H. Seliger (1964). "Quantum yield of ferrioxalate actinometer". In: *Journal of Chemical Physics* 40.2, pp. 519–523. ISSN: 0021-9606. DOI: 10.1063/1.1725147.

Lee, Z. P., K. L. Carder, and R. A. Arnone (2002). "Deriving inherent optical properties from water color: a multiband quasi-analytical algorithm for optically deep water". In: *Applied Optics* 41.27, pp. 5755–5772. DOI: 10.1364/AO.41.005755.

Lester, R. A., A. V. Parisi, M. G. Kimlin, and J. Sabburg (2003). "Optical properties of poly(2,6-dimethyl-1,4-phenylene oxide) film and its potential for a long-term solar ultraviolet dosimeter". In: *Physics in Medicine and Biology* 48.22, pp. 3685–3698. DOI: 10.1088/0031-9155/48/22/005.

Leszczynski, K. (2002). "Advances in Traceability of Solar Ultraviolet Radiation Measurements". PhD thesis. University of Helsinki.

Long, S. P. and J.-E. Hällgren (1987). "Measurement of CO_2 assimilation by plants in the field and the laboratory". In: *Techniques in bioproductivity and photosynthesis*. Ed. by J. Coombes, D. O. Hall, S. P. Long, and J. M. O. Scurlock. Oxford: Pergamon Press Ltd.

Loo, M. V. der and E. de Jonge (2012). *Learning RStudio for R Statistical Computing*. 1st ed. Birmingham, Mumbai: Packt Publishing, p. 126. ISBN: 9781782160601. URL: http://books.google.com/books?hl=en%5C&lr=%5C&id=EE8M9HCJok4C%5C&oi=fnd%5C&pg=PT9%5C&dq=Learning+RStudio+for+R+Statistical+Computing%5C&ots=lzFw3BLTRO%5C&sig=0uCpbnhXK219UhIirR0vZYFtOqI.

Maindonald, J. and W. J. Braun (2010). *Data Analysis and Graphics Using R: An Example-Based Approach*. Cambridge University Press, p. 552. ISBN: 0521762936. URL: http://www.amazon.com/Data-Analysis-Graphics-Using-Example-Based/dp/0521762936.

Manney, G. L., M. L. Santee, M. Rex, N. J. Livesey, M. C. Pitts, P. Veefkind, E. R. Nash, I. Wohltmann, R. Lehmann, L. Froidevaux, et al. (2011). "Unprecedented Arctic ozone loss in 2011". In: *Nature* 478, pp. 469–475. DOI: 10.1038/nature10556.

Marijnissen, J. P. A. and W. M. Star (1987). "Quantitative light dosimetry in vitro and in vivo". In: *Lasers in Medical Science* 2, pp. 235–242. DOI: 10.1007/BF02594166.

Maritorena, S., A. Morel, and B. Gentili (1994). "Diffuse reflectance of oceanic shallow waters: influence of water depth and bottom albedo". In: *Limnology and Oceanography* 39.7, pp. 1689–1703. URL: http://www.jstor.org/stable/2838204.

Markvart, J., E. Rosenqvist, J. M. Aaslyng, and C. .-.-O. Ottosen (2010). "How is Canopy Photosynthesis and Growth of Chrysanthemums Affected by Diffuse and Direct Light?" In: *European Journal of Horticultural Science* 75.6, pp. 253–258. ISSN: 1611-4426.

Massonnet, C., D. Vile, J. Fabre, M. A. Hannah, C. Caldana, J. Lisec, G. T. S. Beemster, R. C. Meyer, G. Messerli, J. T. Gronlund, et al. (2010). "Probing the reproducibility of leaf growth and molecular phenotypes: a comparison of three *Arabidopsis* accessions cultivated in ten laboratories". In: *Plant Physiol* 152, pp. 2142–2157. DOI: 10.1104/pp.109.148338.

Matloff, N. (2011). *The Art of R Programming: A Tour of Statistical Software Design*. No Starch Press, p. 400. ISBN: 1593273843. URL: http://www.amazon.com/The-Art-Programming-Statistical-Software/dp/1593273843.

McKinlay, A. F. and B. L. Diffey (1987). "A reference action spectrum for ultraviolet induced erythema in human skin". In: *CIE Journal* 6, pp. 17–22.

McLeod, A. R. (1997). "Outdoor supplementation systems for studies of the effects of increased uv-b radiation". In: *Plant Ecology* 128, pp. 78–92. DOI: 10.1023/A:1009794427697.

McLeod, A. R., S. C. Fry, G. J. Loake, D. J. Messenger, D. S. Reay, K. A. Smith, and B.-W. Yun (2008). "Ultraviolet radiation drives methane emissions from terrestrial plant pectins". In: *New Phytologist* 180, pp. 124–132. DOI: 10.1111/j.1469-8137.2008.02571.x.

Messenger, D. J., A. R. McLeod, and S. C. Fry (2009). "The role of ultraviolet radiation, photosensitizers, reactive oxygen species and ester groups in mechanisms of methane form-

ation from pectin". In: *Plant Cell and Environment* 32, pp. 1–9. DOI: 10.1111/j.1365-3040.2008.01892.x.

Millar, D. J. and J. W. Hannay (1986). "Phytotoxicity of phthalate plasticisers. II. Site and mode of action". In: *Journal of Experimental Botany* 37, pp. 883–897. DOI: 10.1093/jxb/37.6.898.

Mobley, C. D. (1994). *Light and water - radiative transfer in natural waters*. San Diego: Academic Press. URL: http://www.curtismobley.com/lightandwater.zip.

– (2011). "Fast light calculations for ocean ecosystem and inverse models". In: *Optics Express* 19.20, pp. 18927–18944. DOI: 10.1364/OE.19.018927.

Mobley, C. D. and L. K. Sundman (2003). "Effects of optically shallow bottoms on upwelling radiances: inhomogeneous and sloping bottoms". In: *Limnology and Oceanography, Light in Shallow Waters* 48.1, part 2, pp. 329–336. URL: http://www.jstor.org/stable/3597753.

Mobley, C. D., H. Zhang, and K. J. Voss (2003). "Effects of optically shallow bottoms on upwelling radiances: bidirectional reflectance distribution function effects". In: *Limnology and Oceanography, Light in Shallow Waters* 48.1, part 2, pp. 337–345. URL: http://www.jstor.org/stable/3597754.

Möglich, A., X. Yang, R. A. Ayers, and K. Moffat (2010). "Structure and function of plant photoreceptors". In: *Annu Rev Plant Biol* 61, pp. 21–47. DOI: 10.1146/annurev-arplant-042809-112259.

Monsi, M. and T. Saeki (1953). "Über den Lichfaktor in den Pflanzengesellschaften und seine Bedeutung für die Stoffproduktion". In: *Japanese Journal of Botany* 14, pp. 22–52.

Montalti, M., A. Credi, L. Prodi, and M. T. Gandolfi (2006). *Handbook of Photochemistry*. 3rd ed. Boca Raton, FL, USA: CRC Press. 664 pp. ISBN: 0824723775.

Monteith, J. and M. Unsworth (2008). *Principles of Environmental Physics*. 3rd ed. Academic Press. 440 pp. ISBN: 0125051034.

Morales, L. O., R. Tegelberg, M. Brosché, M. Keinänen, A. Lindfors, and P. J. Aphalo (2010). "Effects of solar UV-A and UV-B radiation on gene expression and phenolic accumulation in Betula pendula leaves". In: *Tree Physiol* 30, pp. 923–934. DOI: 10.1093/treephys/tpq051.

Morel, A. (1974). "Optical properties of pure water and pure sea water". In: *Optical Aspects of Oceanography*. Ed. by N. G. Jerlov and E. Steemann Nielsen. London: Academic Press, pp. 1–24. ISBN: 0123849500.

– (1991). "Light and marine photosynthesis: a spectral model with geochemical and climatological implications". In: *Progress in Oceanography* 26, pp. 263–306. DOI: 10.1016/0079-6611(91)90004-6.

Morel, A. and L. Prieur (1976). "Analyse spectrale de l'absorption par les substances dissoutes (substances jaunes)". In: *Publ. CNEXO* 10.Sect. 1.1.11, pp. 1–9.

Morison, J. I. L. and R. M. Gifford (1984). "Ethylene contamination of CO2 cylinders. Effects on plant growth in CO2 enrichment studies". In: *Plant Physiology* 75, pp. 275–277. DOI: 10.1104/pp.75.1.275.

Murrell, P. (2005a). *R Graphics*. Boca Raton, FL: Chapman & Hall/CRC, p. 301. ISBN: 1-584-88486-X. URL: http://www.stat.auckland.ac.nz/~paul/RGraphics/rgraphics.html.

– (2005b). *R Graphics (Chapman & Hall/CRC The R Series)*. Chapman and Hall/CRC, p. 328. ISBN: 158488486X. URL: http://www.amazon.com/Graphics-Chapman-Hall-CRC-Series/dp/158488486X.

– (2011). *R Graphics, Second Edition (Chapman & Hall/CRC The R Series)*. CRC Press, p. 546. ISBN: 1439831769. URL: http://www.amazon.com/Graphics-Second-Edition-Chapman-Series/dp/1439831769.

Musil, C. F. (1995). "Differential effects of elevated ultraviolet-B radiation on the photochemical and reproductive performances of dicotyledonous and monocotyledonous arid-environment ephemerals". In: *Plant, Cell and Environment* 18, pp. 844–854. DOI: 10.1111/j.1365-3040.1995.tb00593.x.

Musil, C. F., L. O. Björn, M. W. J. Scourfield, and G. E. Bodeker (2002). "How substantial are ultraviolet-B supplementation inaccuracies in experimental square-wave delivery systems?"

In: *Environmental and Experimental Botany* 47.1, pp. 25–38. DOI: DOI:10.1016/S0098-8472(01)00108-3.

Nevas, S., A. Teuber, A. Sperling, and M. Lindemann (2012). "Stability of array spectroradiometers and their suitability for absolute calibrations". In: *Metrologia* 49, S48–S52. DOI: 10.1088/0026-1394/49/2/S48.

Newsham, K. K., A. R. McLeod, P. D. Greenslade, and B. A. Emmett (1996). "Appropriate controls in outdoor UV-B supplementation experiments". In: *Global Change Biology* 2, pp. 319–324. DOI: 10.1111/j.1365-2486.1996.tb00083.x.

Newsham, K. K., A. R. McLeod, J. D. Roberts, P. D. Greenslade, and B. A. Emmet (1997). "Direct effects of elevated UV-B radiation on the decomposition of Quercus robur leaf litter". In: *Oikos* 79, pp. 592–602. URL: http://www.jstor.org/stable/3546903.

Newsham, K. K., P. Splatt, P. A. Coward, P. D. Greenslade, A. R. McLeod, and J. M. Anderson (2001). "Negligible influence of elevated UV-B radiation on leaf litter quality of *Quercus robur*". In: *Soil Biology and Biochemistry* 33, pp. 659–665. DOI: 10.1016/S0038-0717(00)00210-8.

Nobel, P. S. (2009). *Physicochemical and Environmental Plant Physiology*. 4th. Academic Press. 600 pp. ISBN: 0123741432.

Ohde, T. and H. Siegel (2003). "Derivation of immersion factors for the hyperspectral TriOS radiance sensor". In: *Journal of Optics A: Pure and Applied Optics* 5.3, pp. L12–L14. DOI: doi:10.1088/1464-4258/5/3/103.

Oke, T. R. (1988). *Boundary Layer Climates*. 2nd. Routledge. 464 pp. ISBN: 0415043190.

Okerblom, P., T. Lahti, and H. Smolander (1992). "Photosynthesis of a Scots Pine Shoot - A Comparison of 2 Models of Shoot Photosynthesis in Direct and Diffuse Radiation Fields". In: *Tree Physiology* 10.2, pp. 111–125. DOI: 10.1093/treephys/10.2.111.

Parisi, A., P. Schouten, and D. J. Turnbull (2010). "UV dosimeter based on Polyphenylene Oxide for the measurement of UV exposures to plants and humans over extended periods". In: *NIWA 2010 UV Workshop: UV Radiation and its Effects - an Update 2010, 7-9 May 2010*. Queenstown, New Zealand.

Parisi, A., D. J. Turnbull, P. Schouten, N. Downs, and T. J. (2010). "Techniques for solar dosimetry in different environments". In: *UV radiation in global climate change: measurements, modeling and effects on ecosystems*. Ed. by W. Gao, D. L. Schmoldt, and J. R. Slusser. Springer / Shingua University Press, pp. 192–204. ISBN: 978-3-642-03312-4.

Parisi, A. V., V. J. Galea, and C. Randall (2003). "Dosimetric measurement of the visible and UV exposures on field grown soybean plants". In: *Agricultural and Forest Meteorology* 120, pp. 153–160. DOI: 10.1016/j.agrformet.2003.08.012.

Parisi, A. V. and M. G. Kimlin (2004). "Personal solar UV exposure measurements employing modified polysulphone with an extended dynamic range". In: *Photochem Photobiol* 79, pp. 411–415. DOI: 10.1111/j.1751-1097.2004.tb00028.x.

Parisi, A. V. and J. C. F. Wong (1996). "Plant canopy shape and the influences on UV exposures to the canopy". In: *Photochemistry and Photobiology* 63.6, pp. 143–148. DOI: 10.1111/j.1751-1097.1996.tb02434.x.

Parisi, A. V., J. C. F. Wong, and C. Randall (1998). "Simultaneous assessment of photosynthetically active and ultraviolet solar radiation". In: *Agricultural and Forest Meteorology* 92, pp. 97–103. DOI: 10.1016/S0168-1923(98)00094-X.

Parker, C. A. (1953). "A new sensitive chemical actinometer. 1. Some trials with potassium ferrioxalate". In: *Proc. Roy. Soc. London* 220A.1140, pp. 104–116. DOI: 10.1098/rspa.1953.0175.

Passioura, J. (2006). "The perils of pot experiments". In: *Functional Plant Biology* 33.12, pp. 1075–1079. DOI: 10.1071/FP06223.

Paul, N. (2001). "Plant responses to UV-B: time to look beyond stratospheric ozone depletion?" In: *New Phytologist* 150, pp. 5–8. DOI: 10.1046/j.1469-8137.2001.00090.x.

Paul, N. D., R. J. Jacobson, A. Taylor, J. J. Wargent, and J. P. Moore (2005). "The use of wavelength-selective plastic cladding materials in horticulture: understanding of crop and fungal re-

sponses through the assessment of biological spectral weighting functions". In: *Photochem Photobiol* 81.5, pp. 1052–1060. DOI: 10.1562/2004-12-06-RA-392.

Pegau, W. S. and J. R. V. Zaneveld (1993). "Temperature-dependent absorption of water in the red and near-infrared portions of the spectrum". In: *Limnology and Oceanography* 38 (1), pp. 188–192. URL: http://www.jstor.org/stable/2837903.

Petris, G., S. Petrone, and P. Campagnoli (2009). *Dynamic Linear Models with R (Use R!)* Springer, p. 268. ISBN: 0387772375. URL: http://www.amazon.co.uk/Dynamic-Linear-Models-Giovanni-Petris/dp/0387772375.

Petzold, T. (1977). "Volume scattering functions for selected ocean waters". In: *Light in the sea*. Ed. by J. Tyler. Dowden, Hutchinson & Ross, Strouddberg, pp. 152–174. ISBN: 0879332654.

Phoenix, G. K., D. Gwynn-Jones, J. A. Lee, and T. V. Callaghan (2003). "Ecological importance of ambient solar ultraviolet radiation to a sub-arctic heath community". In: *Plant Ecology* 165, pp. 263–273. DOI: 10.1023/A:1022276831900.

Pinheiro, J. C. and D. M. Bates (2000). *Mixed-Effects Models in S and S-Plus*. New York: Springer.

Pinnel, N. (2007). "A method for mapping submersed macrophytes in lakes using hyperspectral remote sensing". PhD thesis. Technische Universität München. URL: http://mediatum2.ub.tum.de/node?id=604557.

Poorter, H., J. Bühler, D. van Dusschoten, J. Climent, and J. A. Postma (2012). "Pot size matters: a meta-analysis of the effects of rooting volume on plant growth". In: *Functional Plant Biology*, DOI: 10.1071/FP12049.

Poorter, H., F. Fiorani, M. Stitt, U. Schurr, A. Finck, Y. Gibon, B. Usadel, R. Munns, O. K. Atkin, F. Tardieu, et al. (2012). "The art of growing plants for experimental purposes: a practical guide for the plant biologist". In: *Functional Plant Biology*. DOI: 10.1071/FP12028.

Pozdnyakov, D. and H. Grassl (2003). *Colour of inland and coastal waters - a methodology for its interpretation*. Berlin/Heidelberg/New York andChichester: Springer Verlag and Praxis Publishing Ltd.

Prahl, S. A., M. Keijzer, S. L. Jacques, and A. J. Welch (1989). "A Monte Carlo Model of Light Propagation in Tissue". In: *SPIE Proceedings of Dosimetry of Laser Radiation in Medicine and Biology*. Ed. by G. J. Müller and D. H. Sliney. Vol. IS 5, pp. 102–111.

Prieur, L. and S. Sathyendranath (1981). "An optical classification of coastal and oceanic waters based on the specific spectral absorption curves of phytoplankton pigments, dissolved organic matter, and other particulate materials". In: *Limnology and Oceanography* 26.4, pp. 671–689. URL: http://www.jstor.org/stable/2836033.

Quaite, F. E., B. M. Sutherland, and J. C. Sutherland (1992). "Action spectrum for DNA damage in alfalfa lowers predicted impact of ozone depletion". In: *Nature* 358, pp. 576–578. DOI: 10.1038/358576a0.

Quan, X. and E. S. Fry (1995). "Empirical equation for the index of refraction of seawater". In: *Applied Optics* 34.18, pp. 3477–3480. DOI: 10.1364/AO.34.003477.

Quinn, G. P. and M. J. Keough (2002). *Experimental Design and Data Analysis for Biologists*. Cambridge, U.K.: Cambridge University Press. xvii + 537. ISBN: 0-521-00976-6.

Quintern, L. E., Y. Furusawa, K. Fukutsu, and H. Holtschmidt (1997). "Characterization and application of UV detector spore films: the sensitivity curve of a new detector system provides good similarity to the action spectrum for UV-induced erythema in human skin". In: *J Photochem Photobiol B* 37, pp. 158–166. DOI: 10.1016/S1011-1344(96)04414-4.

Quintern, L. E., G. Horneck, U. Eschweiler, and H. Bücker (1992). "A biofilm used as ultraviolet-dosimeter". In: *Photochemistry and Photobiology* 55, pp. 389–395. DOI: 10.1111/j.1751-1097.1992.tb04252.x.

Quintern, L. E., M. Puskeppeleit, P. Rainer, S. Weber, S. el Naggar, U. Eschweiler, and G. Horneck (1994). "Continuous dosimetry of the biologically harmful UV-radiation in Antarctica with the biofilm technique". In: *J Photochem Photobiol B* 22, pp. 59–66. DOI: 10.1016/1011-1344(93)06954-2.

Ritz, C. and J. C. Streibig (2009). *Nonlinear Regression with R*. Springer, p. 148. ISBN: 0387096159. URL: http://www.amazon.co.uk/Nonlinear-Regression-R-Use/dp/0387096159.

Rizzini, L., J.-J. Favory, C. Cloix, D. Faggionato, A. O'Hara, E. Kaiserli, R. Baumeister, E. Schäfer, F. Nagy, G. I. Jenkins, et al. (2011). "Perception of UV-B by the *Arabidopsis* UVR8 Protein". In: *Science* 332.6025, pp. 103–106. DOI: 10.1126/science.1200660.

Robert, C. and G. Casella (2009). *Introducing Monte Carlo Methods with R*. Springer, p. 306. ISBN: 1441915753. URL: http://www.amazon.co.uk/Introducing-Monte-Carlo-Methods-Use/dp/1441915753.

Robertson, D. F. (1972). "Solar ultraviolet radiation in relation to human sunburn and skin cancer". PhD thesis. University of Queensland.

Robson, T. M., V. A. Pancotto, C. L. Ballaré, O. E. Sala, A. L. Scopel, and M. M. Caldwell (2004). "Reduction of solar UV-B mediates changes in the *Sphagnum capitulum* microenvironment and the peatland microfungal community". In: *Oecologia* 140, pp. 480–490. DOI: 10.1007/s00442-004-1600-9.

Rockwell, N. C., Y.-S. Su, and J. C. Lagarias (2006). "Phytochrome structure and signaling mechanisms". In: *Annu Rev Plant Biol* 57, pp. 837–858. DOI: 10.1146/annurev.arplant.56.032604.144208.

Roesler, C. S., M. J. Perry, and K. L. Carder (1989). "Modeling in situ phytoplankton absorption from total absorption spectra in productive inland marine waters". In: *Limnology and Oceanography* 34.8, pp. 1510–1523. URL: http://www.jstor.org/stable/2837036.

Rosenqvist, E., F. López Figueroa, I. Gómez, and P. J. Aphalo (2012). "Plant growing conditions". In: *Beyond the Visible: A handbook of best practice in plant UV photobiology*. Ed. by P. J. Aphalo, A. Albert, L. O. Björn, A. R. McLeod, T. M. Robson, and E. Rosenqvist. 1st ed. COST Action FA0906 "UV4growth". Helsinki: University of Helsinki, Department of Biosciences, Division of Plant Biology. Chap. 4, pp. 119–138. ISBN: ISBN 978-952-10-8363-1 (PDF), 978-952-10-8362-4 (paperback). URL: http://hdl.handle.net/10138/37558.

Rousseaux, M. C., S. D. Flint, P. S. Searles, and M. M. Caldwell (2004). "Plant responses to current solar ultraviolet-B radiation and to supplemented solar ultraviolet-B radiation simulating ozone depletion: an experimental comparison". In: *Photochem Photobiol* 80, pp. 224–230. DOI: 10.1562/2004-03-30-RA-129.

Rousseaux, M. C., R. Julkunen-Tiitto, P. S. Searles, A. L. Scopel, P. J. Aphalo, and C. L. Ballaré (2004). "Solar UV-B radiation affects leaf quality and insect herbivory in the southern beech tree *Nothofagus antarctica*". In: *Oecologia* 138, pp. 505–512. DOI: 10.1007/s00442-003-1471-5.

Rozema, J., J. Vandestaaij, L. O. Björn, and M. Caldwell (1997). "UV-B as an environmental factor in plant life—Stress and regulation". In: *Trends in Ecology & Evolution* 12, pp. 22–28. DOI: 10.1016/S0169-5347(96)10062-8.

Ruggaber, A., R. Dlugi, and T. Nakajima (1994). "Modelling radiation quantities and photolysis frequencies in the troposphere". In: *Journal of Atmospheric Chemistry* 18, pp. 171–210. DOI: 10.1007/BF00696813.

Rundel, R. D. (1983). "Action spectra and estimation of biologically effective UV radiation". In: *Physiologia Plantarum* 58, pp. 360–366. DOI: 10.1111/j.1399-3054.1983.tb04195.x.

Rupert, C. S. (1974). "Dosimetric concepts in photobiology". In: *Photochemistry and Photobiology* 20, pp. 203–212. DOI: 10.1111/j.1751-1097.1974.tb06568.x.

Saitou, T., Y. Tachikawa, H. Kamada, M. Watanabe, and H. Harada (1993). "Action spectrum for light-induced formation of adventitious shoots in hairy roots of horseradish". In: *Planta* 189, pp. 590–592. DOI: 10.1007/BF00198224.

Sampath-Wiley, P. and L. S. Jahnke (2011). "A new filter that accurately mimics the solar UV-B spectrum using standard UV lamps: the photochemical properties, stabilization and use of the urate anion liquid filter". In: *Plant Cell Environ* 34, pp. 261–269. DOI: 10.1111/j.1365-3040.2010.02240.x.

Sarkar, D. (2008). *Lattice: Multivariate Data Visualization with R*. 1st ed. Springer, p. 268. ISBN: 0387759689. URL: http://www.amazon.com/Lattice-Multivariate-Data-Visualization-Use/dp/0387759689.

Sathyendranath, S., L. Prieur, and A. Morel (1989). "A three-component model of ocean colour and its application to remote sensing of phytoplankton pigments in coastal waters". In: *International Journal of Remote Sensing* 10.8, pp. 1373–1394. DOI: 10.1080/01431168908903974.

Schouten, P. W., A. V. Parisi, and D. J. Turnbull (2007). "Evaluation of a high exposure solar UV dosimeter for underwater use". In: *Photochemistry and Photobiology* 83, pp. 931–937. DOI: 10.1111/j.1751-1097.2007.00085.x.

– (2008). "Field calibrations of a long-term UV dosimeter for aquatic UV-B exposures". In: *Journal of Photochemistry and Photobiology, B* 91, pp. 108–116. DOI: 10.1016/j.jphotobiol.2008.02.004.

– (2010). "Usage of the polyphenylene oxide dosimeter to measure annual solar erythemal exposures". In: *Photochemistry and Photobiology* 86, pp. 706–710. DOI: 10.1111/j.1751-1097.2010.00720.x.

Schreiner, M., I. Mewis, S. Huyskens-Keil, M. Jansen, R. Zrenner, J. Winkler, N. O'Brian, and A. Krumbein (2012). "UV-B-induced secondary plant metabolites - potential benefits for plant and human health". In: *Critical Reviews in Plant Sciences* 31 (3), pp. 229–240. DOI: doi:10.1080/07352689.2012.664979. URL: http://www.tandfonline.com/doi/abs/10.1080/07352689.2012.664979.

Schwander, H., P. Koepke, A. Ruggaber, T. Nakajima, A. Kaifel, and A. Oppenrieder (2000). *System for transfer of atmospheric radiation STAR - version 2000*.

Schwiegerling, J. (2004). *Field guide to visual and ophthalmic optics*. SPIE Press, Bellingham, WA.

Seckmeyer, G., A. Bais, G. Bernhard, M. Blumthaler, C. R. Booth, P. Disterhoft, P. Eriksen, R. L. McKenzie, M. Miyauchi, and C. Roy (2001). *Instruments to Measure Solar Ultraviolet Radiation - Part 1: Spectral Instruments*. Tech. rep. WMO/TD-No. 1066, GAW Report No. 125. Geneva: World Meteorological Organization.

Seckmeyer, G., A. Bais, G. Bernhard, M. Blumthaler, C. R. Booth, K. Lantz, R. L. McKenzie, P. Disterhoft, and A. Webb (2005). *Instruments to Measure Solar Ultraviolet Radiation Part 2: Broadband Instruments Measuring Erythemally Weighted Solar Irradiance*. WMO-GAW Report 164. Geneva, Switzerland: World Meteorological Organization (WMO).

Seckmeyer, G., A. Bais, G. Bernhard, M. Blumthaler, S. Drüke, P. Kiedron, K. Lantz, R. L. McKenzie, S. Riechelmann, N. Kouremeti, et al. (2010). *Instruments to Measure Solar Ultraviolet Radiation - Part 4: Array Spectroradiometers*. GAW Report 191. Geneva: Global Atmosphere Watch, World Meteorological Organization. URL: http://www.wmo.int/pages/prog/arep/gaw/documents/GAW191_TD_No_1538_web.pdf.

Seckmeyer, G., A. Bais, G. Bernhard, M. Blumthaler, B. Johnsen, K. Lantz, and R. McKenzie (2010). *Instruments to Measure Solar Ultraviolet Radiation - Part 3: Multi-channel filter instruments*. Tech. rep. WMO/TD-No. 1537, GAW Report No. 190. Geneva: World Meteorological Organization.

Seckmeyer, G. and H.-D. Payer (1993). "A new sunlight simulator for ecological research on plants". In: *Journal of Photochemistry and Photobiology B: Biology* 21.2–3, pp. 175–181. DOI: 10.1016/1011-1344(93)80180-H.

Seliger, H. H. and W. D. McElroy (1965). *Light: Physical and biological action*. New York and London: Academic Press. xi+417. ISBN: 0126358508.

Sellaro, R., M. Crepy, S. A. Trupkin, E. Karayekov, A. S. Buchovsky, C. Rossi, and J. J. Casal (2010). "Cryptochrome as a sensor of the blue / green ratio of natural radiation in Arabidopsis." eng. In: *Plant Physiology* 154.1, pp. 401–409. DOI: 10.1104/pp.110.160820.

Setlow, R. B. (1974). "The wavelengths in sunlight effective in producing skin cancer: a theoretical analysis". In: *Procceedings of the National Academy of Sciences of the U.S.A.* 71, pp. 3363–3366.

Shimazaki, K.-I., M. Doi, S. M. Assmann, and T. Kinoshita (2007). "Light Regulation of Stomatal Movement". In: *Annual Review of Plant Biology* 58, pp. 219–247. DOI: 10.1146/annurev.arplant.57.032905.105434.

Shropshire, W. (1972). "Action spectroscopy". In: *Phytochrome*. Ed. by K. Mitrakos and W. Shropshire. London: Academic Press, pp. 161–181. ISBN: 0125005504.

Sliney, D. H. (2007). "Radiometric quantities and units used in photobiology and photochemistry: recommendations of the Commission Internationale de L'Eclairage (International Commission on Illumination)". In: *Photochemistry and Photobiology* 83, pp. 425–432. DOI: 10.1562/2006-11-14-RA-1081 (cit. on p. xv).

Smith, H. (1981). *Plants and the Daylight Spectrum*. London: Academic Press.

Smith, H. F. (1957). "Interpretation of adjusted treatment means and regressions in analysis of covariance". In: *Biometrics* 13, pp. 281–308. URL: http://www.jstor.org/stable/2527917.

Smith, R. C. and K. S. Baker (1981). "Optical properties of the clearest natural waters (200-800 nm)". In: *Applied Optics* 20.2, pp. 177–184. DOI: 10.1364/AO.20.000177.

Smith, R. C. and J. E. Tyler (1976). "Transmission of solar radiation into natural waters". In: Photochemical and Photobiological Reviews 1. Ed. by K. C. Smith, pp. 117–155.

Smoluchowski, M. (1908). "Molekular-kinetische Theorie der Opaleszenz von Gasen im kritischen Zustande, sowie einiger verwandter Erscheinungen". In: *Annalen der Physik* 25, pp. 205–226.

Soetaert, K., J. Cash, and F. Mazzia. *Solving Differential Equations in R*. Springer. ISBN: 3642280692. URL: http://www.amazon.com/Solving-Differential-Equations-Karline-Soetaert/dp/3642280692.

Stanghellini, C. (1987). *Transpiration of greenhouse crops—an aid to climate management*. Wageningen, NL: Intituut voor Mechanisatie, Arbeid en Gebouwen.

Stanhill, G. and S. Cohen (2001). "Global dimming: a review of the evidence for a widespread and significant reduction in global radiation with discussion of its probable causes and possible agricultural consequences". In: *Agricultural and Forest Meteorology* 107, pp. 255–278. DOI: 10.1016/S0168-1923(00)00241-0.

Stanhill, G. and H. Z. Enoch, eds. (1999). *Greenhouse Ecosystems, Ecosystems of the world*. Vol. 20. Amsterdam, NL: Elsevier. 434 pp. ISBN: 0444882677.

Stanton, J. (2013). *An Introduction to Data Science*. Version 3. Syracuse University, p. 196. URL: http://jsresearch.net/wiki/projects/teachdatascience.

Tattar, P. N. (2013). *R Statistical Application Development by Example Beginner's Guide*. 1st ed. Birmingham, Mumbai: Packt Publishing, p. 345. ISBN: 9781849519441.

Technical Committee ISO/TC 20, A., S. s. space vehicles Subcommittee SC 14, and operations (2007). *Space environment (natural and artificial) – Process for determining solar irradiances*. English. Satandard 21348:2007. ISO (the International Organization for Standardization). 12 pp. URL: http://www.iso.org/iso/catalogue_detail.htm?csnumber=39911.

Teetor, P. (2011). *R Cookbook*. 1st ed. Sebastopol: O'Reilly Media, p. 436. ISBN: 9780596809157.

Tennessen, D. J., E. L. Singsaas, and T. D. Sharkey (1994). "Light-emitting diodes as a light source for photosynthesis research". In: *Photosynthesis Research* 39, pp. 85–92. DOI: 10.1007/BF00027146.

Tevini, M. (1993). "Effects of Enhanced UV-B Radiation on Terrestrial Plants". In: *UV-B Radiation and Ozone Depletion: Effects on Humans, Animals, Plants, Microorganisms, and Materials*. Ed. by M. Tevini. Boca Raton: Lewis Publishers, pp. 125–153. ISBN: 0-87371-911-5.

Thiel, S., T. Döhring, M. Köfferlein, A. Kosak, P. Martin, and H. K. Seidlitz (1996a). "A Phytotron for Plant Stress Research: How Far Can Artificial Lighting Compare to Natural Sunlight?" In: *Journal of Plant Physiology* 148.3–4, pp. 456–463. DOI: 10.1016/S0176-1617(96)80279-3.

Thiel, S., T. Döhring, M. Köfferlein, A. Kosak, P. Martin, and H. K. Seidlitz (1996b). "A phytotron for plant stress research: how far can artificial lighting compare to natural sunlight?" In: *Journal of Plant Physiology* 148, pp. 456–463. DOI: 10.1016/S0176-1617(96)80279-3.

Thimijan, R. W., H. R. Carns, and L. E. Campbell (1978). *Final Report (EPA-IAG-D6-0168): Radiation sources and related environmental control for biological and climatic effects UV research (BACER)*. Tech. rep. Washington, DC: Environmental Protection Agency (cit. on p. xv).

Tukey, J. W. (1991). "The Philosophy of Multiple Comparisons". In: *Statistical Science* 6.1, pp. 100–116. DOI: 10.1214/ss/1177011945.

Turnbull, D. J. and P. W. Schouten (2008). "Utilising polyphenylene oxide for high exposure solar UVA dosimetry". In: *Atmospheric Chemistry and Physics* 8.10, pp. 2759–2762. DOI: 10.5194/acp-8-2759-2008.

Tyler, J. E. (1968). "The Secchi disc". In: *Limnology and Oceanography* 13.1, pp. 1–6. URL: http://www.jstor.org/stable/2833820.

UNEP (2011). *2010 assessment report of the Environmental effects of ozone depletion and its interactions with climate change*. Photochemical and Photobiological Sciences 10(2), 165–320. Also published by UNEP.

Urban, O., D. Janous, M. Acosta, R. Czerny, I. Markova, M. Navratil, M. Pavelka, R. Pokorny, M. Sprtova, R. Zhang, et al. (2007). "Ecophysiological controls over the net ecosystem exchange of mountain spruce stand. Comparison of the response in direct vs. diffuse solar radiation". In: *Global Change Biology* 13, pp. 157–168. DOI: 10.1111/j.1365-2486.2006.01265.x.

Urban, O., K. Klem, A. Ac, K. Havránková, P. Holisová, M. Navrátil, M. Zitová, K. Kozlová, R. Pokorný, M. Sprtová, et al. (2012). "Impact of clear and cloudy sky conditions on the vertical distribution of photosynthetic CO_2 uptake within a spruce canopy". In: *Functional Ecology* 26, pp. 46–55. DOI: 10.1111/j.1365-2435.2011.01934.x.

Van den Boogaard, R., J. Harbinson, M. Mensink, and J. Ruijsch (2001). "Effects of quality and daily distribution of irradiance on photosynthetic electron transport and CO2 fixation in tomato". In: *Proceedings of the 12th International Congress on Photosynthesis, Brisbane, Australia*. Vol. S28-030,

Veit, M., T. Bilger, T. Muhlbauer, W. Brummet, and K. Winter (1996). "Diurnal changes in flavonoids". In: *Journal of Plant Physiology* 148.3-4, pp. 478–482. DOI: 10.1016/S0176-1617(96)80282-3.

Venables, W. N. and B. D. Ripley (1999). *Modern Applied Statistics with {S-PLUS}*. 3rd. Statistics and Computing. New York: Springer, pp. x + 501. ISBN: 0 387 98825 4.

– (2000). *S Programming*. Statistics and Computing. New York: Springer, pp. x + 264. ISBN: 0 387 98966 8.

Venables, W. N. and B. D. Ripley (2002). *Modern Applied Statistics with {S}*. 4th. New York: Springer. ISBN: 0-387-95457-0. URL: http://www.stats.ox.ac.uk/pub/MASS4/.

Verzani, J. (2004). *Using R for Introductory Statistics*. Chapman & Hall/CRC, p. 432. ISBN: 1584884509.

Visser, A. J., M. Tosserams, M. W. Groen, G. W. H. Magendans, and J. Rozema (1997). "The combined effects of CO_2 concentration and solar UV-B radiation on faba bean grown in open-top chambers". In: *Plant, Cell and Environment* 20.2, pp. 189–199. DOI: 10.1046/j.1365-3040.1997.d01-64.x.

Vogelmann, T. C. and L. O. Björn (1984). "Measurement of light gradients and spectral regime in plant tissue with a fiber optic probe". In: *Physiologia Plantarum* 60, pp. 361–368. DOI: 10.1111/j.1399-3054.1984.tb06076.x.

Vogelmann, T. C. and J. R. Evans (2002). "Profiles of light absorption and chlorophyll within spinach leaves from chlorophyll fluorescence". In: *Plant Cell and Environment* 25, pp. 1313–1323. DOI: 10.1046/j.1365-3040.2002.00910.x.

Vogelmann, T. C. and T. Han (2000). "Measurements of gradients of absorbed light in spinach leaves from chlorophyll fluorescence profiles". In: *Plant Cell and Environment* 23, pp. 1303–1311. DOI: 10.1046/j.1365-3040.2000.00649.x.

Wang, L.-. H., S. L. Jacques, and L.-. Q. Zheng (1995). "MCML - Monte Carlo modeling of photon transport in multi-layered tissues". In: *Computer Methods and Programs in Biomedicine* 47, pp. 131–146. DOI: 10.1016/0169-2607(95)01640-F.

Wargent, J. J., V. C. Gegas, G. I. Jenkins, J. H. Doonan, and N. D. Paul (2009). "UVR8 in *Arabidopsis thaliana* regulates multiple aspects of cellular differentiation during leaf development in response to ultraviolet B radiation". In: *New Phytologist* 183.2, pp. 315–326. DOI: 10.1111/j.1469-8137.2009.02855.x.

Watanabe, M., M. Furuya, Y. Miyoshi, Y. Inoue, I. Iwahashi, and K. Matsumoto (1982). "Design and Performance of The Okazaki Large Spectrograph for Photobiological Research". In: *Pho-*

tochemistry and Photobiology 36, pp. 491–498. DOI: 10.1111/j.1751-1097.1982.tb04407.x.

Webb, A., J. Gröbner, and M. Blumthaler (2006). *A Practical Guide to Operating Broadband Instruments Measuring Erythemally Weighted Irradiance*. Tech. rep. Produced by the joint efforts of WMO SAG UV, Working Group 4 of COST-726 Action "Long Term Changes, and Climatology of UV Radiation over Europe".

Webb, A. R., H. Slaper, P. Koepke, and A. W. Schmalwieser (2011). "Know your standard: clarifying the CIE erythema action spectrum". In: *Photochemistry and Photobiology* 87, pp. 483–486. DOI: 10.1111/j.1751-1097.2010.00871.x.

Wehrli, C. (1985). *Extraterrestrial solar spectrum*. PMOD/WRC Publication 615. Physikalisch-Meteorologisches Observatorium und World Radiation Center Davos Dorf, Switzerland.

WHO (2002). *Global solar UV index: a practical guide*. Tech. rep. ISBN 92 4 159007 6. World Health Organization. URL: http://www.unep.org/PDF/Solar_Index_Guide.pdf.

Wickham, H. (2009). *ggplot2: Elegant Graphics for Data Analysis*. 2nd Printi. Springer, p. 224. ISBN: 0387981403. URL: http://www.amazon.com/ggplot2-Elegant-Graphics-Data-Analysis/dp/0387981403.

Wickham, H. (2014a). *Advanced R*. Chapman & Hall/CRC The R Series. CRC Press. ISBN: 9781466586970. URL: https://books.google.fi/books?id=G5PNBQAAQBAJ.

Wickham, H. (2014b). "Tidy Data". In: *Journal of Statistical Software* 59.10, ??–?? ISSN: 1548-7660. URL: http://www.jstatsoft.org/v59/i10.

Wickham, H. (2015). *R Packages*. O'Reilly Media. ISBN: 9781491910542. URL: https://books.google.fi/books?id=eqOxBwAAQBAJ.

WMO (2008). *Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8*. Tech. rep. Seventh edition. World Meteorological Organization.

Wu, D., Q. Hu, Z. Yan, W. Chen, C. Yan, X. Huang, J. Zhang, P. Yang, H. Deng, J. Wang, et al. (2012). "Structural basis of ultraviolet-B perception by UVR8". In: *Nature* 484, pp. 214–219. DOI: 10.1038/nature10931.

Wu, M., E. Grahn, L. A. Eriksson, and A. Strid (2011). "Computational evidence for the role of *Arabidopsis thaliana* UVR8 as UV-B photoreceptor and identification of its chromophore amino acids". In: *Journal of Chemical Information and Modeling* 51, pp. 1287–1295. DOI: 10.1021/ci200017f.

Xie, Y. (2013). *Dynamic Documents with R and knitr (Chapman & Hall/CRC The R Series)*. Chapman and Hall/CRC, p. 216. ISBN: 1482203537. URL: http://www.amazon.com/Dynamic-Documents-knitr-Chapman-Series/dp/1482203537.

Xu, C. and J. H. Sullivan (2010). "Reviewing the Technical Designs for Experiments with Ultraviolet-B Radiation and Impact on Photosynthesis, DNA and Secondary Metabolism". In: *Journal of Integrative Plant Biology* 52, pp. 377–387. DOI: 10.1111/j.1744-7909.2010.00939.x.

Ylianttila, L., R. Visuri, L. Huurto, and K. Jokela (2005). "Evaluation of a single-monochromator diode array spectroradiometer for sunbed UV-radiation measurements". In: *Photochemistry and Photobiology* 81, pp. 333–341. DOI: 10.1562/2004-06-02-RA-184.

Zuur, A., E. N. Ieno, and G. M. Smith (2007). *Analysing Ecological Data (Statistics for Biology and Health)*. Springer, p. 672. ISBN: 0387459677. URL: http://www.amazon.com/Analysing-Ecological-Statistics-Biology-Health/dp/0387459677.

Zuur, A., E. N. Ieno, N. Walker, A. A. Saveliev, and G. M. Smith (2009). *Mixed Effects Models and Extensions in Ecology with R*. New York: Springer, p. 574. ISBN: 978-0-387-87457-9. URL: http://www.amazon.com/Effects-Extensions-Ecology-Statistics-Biology/dp/0387874577.

Zuur, A. F., E. N. Ieno, and E. Meesters (2009). *A Beginner's Guide to R*. 1st ed. Springer, p. 236. ISBN: 0387938362. URL: http://www.amazon.com/Beginners-Guide-Use-Alain-Zuur/dp/0387938362.

Glossary

absorbance $A = \log E_0/E_1$, where E_0 is the incident irradiance, and E_1 is the transmitted irradiance. xv

absorptance radiation that is absorbed by an object, as a fraction of the incident irradiance: $\alpha = E_{\text{abs}}/E_0$, where E_0 is the incident irradiance and E_{abs} is the absorbed irradiance. xv

biological spectral weighting function a function used to estimate the biological effect of radiation. It is convoluted—i.e. multiplied wavelength by wavelength—with the spectral irradiance of a source of UV radiation to obtain a biologically effective irradiance. xv

CRAN, Comprehensive R Archive Network A network of software and documentation repositories for R packages and R itself. 45

direct radiation solar radiation that arrives directly at the ground level, without being scattered by gases and particles of the atmosphere. 16, 21

global radiation total solar radiation arriving at ground level. It is the sum of direct and diffuse radiation. 16, *see* direct radiation

isotropic radiation is isotropic when it arrives equally from all directions, e.g. it is completely diffuse. *see* scattered or 'diffuse' radiation

photosynthetic photon flux density another name for 'PAR photon irradiance'. xvii

photosynthetically active radiation radiation driving photosynthesis in higher plants, it describes a wavelength range—i.e. λ =400–700 nm—but does not define whether an energy or photon quantity is being used. xvi

proportional-integral-derivative a *proportional integral derivative* controller (PID controller) is a control loop feedback mechanism. A PID controller calculates an "error" value as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error by adjusting the process control inputs. A well tuned PID controller (with correct parameters) minimizes overshoot and transient deviations, by adjusting, for example, the dimming in a modulated system based on the size of the error and the response characteristics of the controlled system. xvi

radiation amplification factor gives the percent change in biologically effective UV irradiance for a 1% change in stratospheric ozone column thickness. Its value varies with the BSWF used in the calculation. xvii

reflectance radiation that is reflected by an object, as a fraction of the incident irradiance: $\rho = E_{\text{rfl}}/E_0$, where E_0 is the incident irradiance and E_{rfl} is the reflected irradiance. xv

scattered or 'diffuse' radiation solar radiation that arrives at ground level after being scattered by gases and particles of the atmosphere, also called 'diffuse radiation'. 16

transmittance radiation that is transmitted by an object, as a fraction of the incident irradiance: $\tau = E_{\text{trs}}/E_0$, where E_0 is the incident irradiance and E_{trs} is the transmitted irradiance. xv

Part VII.

Appendix

A.

Build information

```
Sys.info()
```

```
##        sysname        release        version
##      "Windows"       "10 x64"  "build 10586"
##       nodename        machine          login
##        "MUSTI"       "x86-64"       "aphalo"
##           user effective_user
##       "aphalo"       "aphalo"
```

```
sessionInfo()
```

```
## R version 3.3.0 (2016-05-03)
## Platform: x86_64-w64-mingw32/x64 (64-bit)
## Running under: Windows 10 x64 (build 10586)
##
## locale:
## [1] LC_COLLATE=English_United States.1252
## [2] LC_CTYPE=English_United States.1252
## [3] LC_MONETARY=English_United States.1252
## [4] LC_NUMERIC=C
## [5] LC_TIME=English_United States.1252
##
## attached base packages:
## [1] tools     stats     graphics  grDevices
## [5] utils     datasets  base
##
## other attached packages:
## [1] stringr_1.0.0 knitr_1.13.1
##
## loaded via a namespace (and not attached):
## [1] magrittr_1.5  formatR_1.4   stringi_1.0-1
## [4] highr_0.6     methods_3.3.0 evaluate_0.9
```