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Interactive Comment

Interactive comment on "Personal UV exposure on a ski-field at an alpine site" *by* A. M. Siani et al.

A. M. Siani et al.

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General comments: This is a well written paper providing new and interesting information.

Authors comment, AC: The authors thank the referee for the positive comments and the constructive criticism.

However, as already noted by the other reviewer, there is too little and partly unclear information about the calibration procedures and its uncertainties. Considering the uncertainties of well- maintained spectroradiometers on which the calibration of well maintained broadband instruments is based, it is extremely unlikely that an uncertainty analysis would give uncertainties of about 10% only. Instead much higher uncertainties must be assumed.

AC: See the attached modified sections 2.3 and 2.4

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Interactive Discussion

Discussion Paper

On page 2750, line 20, or on page 2751, line 21, there is no hint how the estimate of 10% or 20% may have been assessed.

AC: In section 2.5 Exposure Ratio will be better defined as follows: "Exposure Ratio (ER) is defined as the ratio between the personal dose on a selected anatomical site (as defined in section 2.4) and the corresponding ambient dose on a horizontal plane (as defined in section 2.3) during the same exposure period. ER provides the percentage of ambient dose received by the anatomical location. The personal dose was derived using the PS calibration curve and the ambient dose was measured by the radiometer installed at the site under study. The ER is less dependent on the environmental exposure conditions than the personal dose, allowing to compare different exposure conditions and periods. The use of the ER attenuates the effect of local environmental factors accentuating individual habits and posture during exposure (Antoine et al., 2007). ER can be expressed by the following formula:

ER = DosePS/DoseHoriz = c(DeltaA +Delta A^2+9DeltaA^3)/DoseHoriz (2)

DosePS is the personal dose as measured by the PS dosimeter worn by the volunteers and retrieved from the calibration curve at the site. DoseHoriz is the corresponding ambient dose on a horizontal plane provided by the radiometer. The overall uncertainty on ER was estimated to be +/- 20% as derived from the error propagation formula taking into account an uncertainty of 10% in the ambient dose provided by radiometer combined with the uncertainty of personal dose of 10%."

Antoine, M, Sottas, P.E., Bulliard J.L., Venez, D.: Effective exposure to solar UV in building workers: influence of local and individual factors”, Journal of Exposure Science and Environmental Epidemiology, 17, 58-68, 2007.

In addition the dependence of c on altitude, orientation and shadow dependence suggest severe calibration problems that are probably caused by the spectral mismatch between the broadband meter and polysulphone badges. Since these calibration issues partly touch the validity of the results, a major reanalysis of the calibration pro-

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cedure and its uncertainty analysis is recommended. Equation (1) can only be used if the spectrum remains constant, which is the case here obviously. In the absence of such a detailed analysis, which is probably beyond the scope of this paper, much more careful statements about the uncertainties are required.

AC: See the modified section 2.4

In addition the physical quantities are often not clear:

Page 2746, line 23

AC:In the abstract "UV intensities" will be replaced by "UV effective doses"

page 2748, line 16: What is a "UV intensity?"

AC: UV intensity will be replaced by UV irradiance

What is an ambient dose (from the context it can be guessed it the erythemally weighted irradiance on a horizontal surface)?

AC: Ambient dose will be better defined in section 2.3 see below.

How is exposure defined? On page 2756, line 20, there is a statement that the exposure is higher on ski-fields than on the beach. However, for the actual exposure (at least in the sense where term in usually used) the exposed area plays a role as well. The quantities need to clarified.

AC: A better definition of personal dose or exposure of a specific anatomical site is provided in the modified section 2.4.

See the modified sections 2.3, 2.4 and 2.5.

Following the suggestion by referee 1 the paragraph from L14 to L21 will be inserted in the conclusions.

Specific comments: Page 2746, line 20: the abstract should be written in a way that it is understandable for those who do not know what L* and b* is, or it should be properly

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explained.

AC: In the abstract the L*,a* and b* will explained as follows: "Measuring skin colour in the CIE L*, a*, b* system was also carried out on the forearm and cheek of each volunteers before and after exposure. L* is the luminance, a* is a measure of redness and b* is a measure of yellowness."

Page 2747, line13: the statement is correct, but the old references from the 60s (Bener) are missing

AC: The following references will be included in the introduction and in the list of references:

Bener, P.: Investigation of the spectral intensity of ultraviolet sky and sun+sky radiation (between 297.5 and 370 nm) under different conditions of cloudless weather at 1590m a.s.l., Contract AF61(052)-54, Technical Summary n.1, Physikalisch-Meteorologisches Observatorium Davos, Davos Platz, Switzerland, 1960.

Bener, P.: The diurnal and annual variations of the spectral intensity of UV sky and global radiation on cloudless days at Davos, 1590 m a.sl., Contract AF61(052)-618, Technical Summary n.2, Physikalisch-Meteorologisches Observatorium Davos, Davos Platz, Switzerland, 1963.

Page 2747, line 16: the effect of clouds below the observation site is another important factor (e.g. published by McKenzie et.al., or Seckmeyer et.al. 1997)

AC: The following statement will be added at pag2747 L16: "In addition broken clouds can produce high values of UV irradiances (Seckmeyer et al.1997) and the enhancements can be up to 25% (WMO, 2007)."

The following references will be included in the list of the references:

Seckmeyer, G., Mayer, B., Bernhard, G., Erb, R., Albold, A., Jager, H., Stockwell, W.R.: New maximum UV irradiance levels observed in Central Europe Atmos. Environ.,

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31(18), 2971-2976, 1997;

WMO Scientific Assessment of ozone Depletion: 2006, Report 50, Surface Ultraviolet Radiation: Past, Present, and Future, Chapter 7, 7.1-7.54, 2007.

Page 2752, line 12 and line 15: it would good to give references, where these tests are described in the scientific literature

AC: The following references will be included in the section 3.5 and in list of references:

Wilcoxon, F. : Individual comparisons by ranking methods, Biometrica Bulletin, 1, 80-83, 1945.

Friedman, M: The use of ranks to avoid the assumption of normality implicit in the analysis of variance. Journal of the American Statistical Association, 32, 675-701,1937.

Page 2752, line 22: replace median by average or is something else meant?

AC: It will be specified at section 3.5 as follows "The median was used instead of the mean value as statistical parameter when the values do not show to have a Gaussian distribution. The median is a measure of central tendency of a sample for which one-half (50%) of the observations will lie above that value and one-half will lie below that value."

Page 2753, line 1: how were the skin types determined?

AC: In page 2749 line 19 how the skin types were determined will be included in the text "In addition the research team of Sapienza-University of Rome, on the basis of the observation of hair and eye colours, skin pigmentation and questions on burning and tanning tendency, diagnosed the skin photo-type of participants according to the classification of Fitzpatrick skin types (1974), before each field campaign."

Fitzpatrick, T.B., M., Pathak, J.A., Parrish: Protection of human skin against the effects of the sunburn ultraviolet (290–320 nm). Sunlight and Man: Normal and Abnormal Photobiologic Responses, eds MA Pathak, LC Harber, M Seiji & A Kukita;

consulting ed. TB Fitzpatrick, Tokyo: University of Tokyo Press, 751, 1974.

Page 2753, line 22: this is what the authors can hope, but how can they know that?

AC: Volunteers were also selected on the basis of their interest, enthusiasm and responsibility. These criteria allowed to ensure a high rate of return. In fact volunteers after the field campaigns were asked about the correct use of dosimeters and this was verified measuring the post absorbance that was within the acceptable range of values.

Page 2754, line 2: it must be doubted that the conditions were identical. If there is a strong influence of snow albedo, it should be noted that the snow albedo is changing drastically with snow age (e.g. Wuttke et.al. 2006) and this in turn changes the UV exposure.

AC: Section 3.2 will be modified as follows:

"In both campaigns ambient UV doses were recorded from 10:00 LT to 16:00 LT under almost clear sky conditions (April 1st was completely cloudy and on April 2nd scattered conditions occurred in the afternoon, but on this day the volunteers wore the dosimeters only in the first part of the day). Fig.2 shows ambient dose rate recorded at La Thuile-Les Suches during the spring campaign expressed as the dimensionless UV Index (ambient dose rate divided by 25mWm-2 ,Cost-713, 2000). In that period daily total ozone ranged from 330 DU to 369 DU and solar zenith angles (SZA) were $41^\circ < SZA < 54^\circ$. The data presented in this figure clearly shows the intense environmental UV radiation that the participants were exposed to at this site. In winter a total ozone of 300 DU and $64^\circ < SZA < 70^\circ$ were experienced and UV index peaks was about 2. Assuming a comparable environment within days of each campaign, the average of ambient doses at each time interval for both campaigns were: in spring 1018 Jm-2 (10:00-12:00 LT), 1130 Jm-2 (12:00-14:00 LT), 825 Jm-2 (14:00-16:00 LT); in winter 246 Jm-2 (10:00-12:00 LT), 349 (12:00-14:00 LT), 183 Jm-2 (14:00-16:00 LT). It can be noticed that the highest values occurred between 12:00 and 14:00 LT due to the shorter atmospheric path of radiation and the smaller solar zenith angle."

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Page 2754, line 7: the dependence of UV irradiance on altitude cannot be described by a single number. It depends on many parameters and is a function of wavelength. This should be mentioned (reference: Seckmeyer G., Mayer B., Bernhard G., Albold A., Erb R., Jaeger H., Stockwell W.R.: New Maximum UV Irradiance Levels Observed in Central Europe, Atmospheric Environment, Vol. 31, No 18, pp 2971-2976, 1997)

AC: In section 3.3 the above suggestion will be included as follows: "Measurements of ambient doses for the calibration curve were carried out on March 31. In that day the comparison among the ambient doses recorded at the three sites at different altitudes showed a percentage differences of 37.7% /1531m (equivalent to 24%/1000m) between La Thuile-Les-Suches and Saint Christophe and of 22.1%/ 1071m (equivalent 20%/1000m) between Les Granges and Saint Christophe. It can be noticed that the dependence of UV irradiance on altitude cannot be described by a single number because it depends on many parameters and is a function of wavelength. The observed variability is caused non solely by the altitude but it depends by a combination of several factors such as Rayleigh scattering, cloud effects, tropospheric ozone and albedo (Seckmeyer et al., 1997). Such variability was also observed in the c values of the calibration curves: a c value of (1.69+/-0.02) kJm-2 at La Thuile-Les Suches, of (1.47+/-0.01) kJm-2 at Les Granges and of (1.24+/-0.01) kJm-2 at Saint Christophe. It can be noticed that the c value is higher for the higher site and all values are higher than those obtained theoretically (0.94+/-0.19) kJm-2 according to Casale's study (2006) when only solar zenith angles and total ozone amounts related to the campaigns were taken into account."

The following reference will be included in the list of references: Seckmeyer, G., Mayer, B., Bernhard, G., Albold, A., Erb, R., Jaeger, H., Stockwell, W.R.: New Maximum UV Irradiance Levels Observed in Central Europe, Atmospheric Environment, 31, 18, 2971-2976, 1997.

Page 2757, line 21: this is an important message for the public, which may be emphasized in the abstract

AC: The following statement will be added: "Given the high levels of exposure observed in the present study, dedicated public heath messages on the improvement of the efficacy of sun-protection behaviours (proper application and re-application of sunscreen and protective measures such as hats and sun glasses) should be adopted."

2.3 Ambient UV dose measurements The ambient erythemal dose (hereafter called ambient dose) is defined as the incident erythemally weighted irradiance (dose rate) on a horizontal surface over a specified period of time, expressed in Joules per square meter, Jm-2 (Parisi et al., 2005). In this study the C.I.E erythemal action spectrum (1987) was considered. Ambient doses were measured using a calibrated broad-band UV-S-AE-T radiometer (Kipp&Zonen, The Netherlands), installed, for both field campaigns, on the roof of the building of Espace S. Bernardo cable car directly on the ski-field at La Thuile-Les Suches (45.7°N, 6.6°E, 2100 m a.s.l.). In addition UV doses were also recorded by a broad-band radiometer (model UVB-1, Yankee Environmental System, MA, USA) operational at the headquarter of ARPA at Saint Christophe, Aosta (45.8°N, 7.4°E, 569m a.s.l.), and by a second UV-S-AE-T broad-band radiometer in operation at ARPA station at Les Granges (45.7°N, 6.6°E, 1640m a.s.l.). The radiometers have a spectral response approximately matching the skin erythemal action spectrum (C.I.E., 1987) and they provide the erythemal dose rate between 280 and 400 nm with a sampling time of 10 seconds. All UV instruments belong to ARPA Valle d'Aosta. The calibration of the three broad-band radiometers is performed by Calibration Measurement Softwaresolutions (CMS) in Austria every year with the reference to the CMS Bentham spectroradiometer. The estimated uncertainty of the spectroradiometer is 5%. Values of erythemal dose rates are obtained using a calibration matrix (Groebner et al., 2006) as a function of solar zenith angle and total ozone amounts. The ozone data were obtained using the Ozone Monitoring Instrument (OMI) at the time of measurement. In addition periodic checks of the three broad-band radiometers are performed by ARPA with reference to a Bentham double monochromator spectroradiometer installed at Saint Christophe according to Seckmeyer et al., 2006. The ARPA spectroradiometer is intercompared with the travelling standard QASUME spectrora-

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diometer (Groebner et al., 2005) from the PMOD/WRC (Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center) every two years and is calibrated every month by a local operator by means of 200W calibration lamps. The lamps were calibrated by the PMOD/WRC. The overall uncertainty of broad-band radiometers combined with the uncertainty of the reference spectroradiometer is estimated to be 10%.

C.I.E. (Commission Internationale d'Eclairage Research Note. A reference action spectrum for ultraviolet induced erythema in human skin. CIE J 1987; 6: 17-22).

Gröbner,J., Hülsen, G., Vuilleumier, L., Blumthaler, M., Vilaplana, Walker, D., Gil, J. E.,: Report of the PMOD/WRC-COST Calibration and Intercomparison of Erythemal radiometers Davos, Switzerland 28 July – 23 August 2006,(http://i115srv.vu-wien.ac.at/uv/COST726/Cost726.htm

Gröbner, J., Schreder J., Kazadzis S, Bais, A. F., Blumthaler, M., Görts P., Tax, R., Koskela, T., Seckmeyer, G., Webb, A. R., Rembges, D.:Traveling reference spectroradiometer for routine quality assurance of spectral solar ultraviolet irradiance measurements, Appl. Opt., 44, 5321–5331, 2005.

Ozone monitoring Instrument (OMI), ozone data available at: http://jwocky.gsfc.nasa.gov/ozone/ozone_v8.html, 2008.

Parisi, A.V.: Physics concepts of solar ultraviolet radiation by distance education, Eur J Phys, 26(2), 313-320, 2005.

Seckmeyer, G., Bais A.,F, G. Bernhard, M. Blumthaler, C. R. Booth, R. L. Lantz, R. L. McKenzie, P. Disterhoft, and A. Webb:Instruments to measure solar ultraviolet radiation. Part 2: Broadband instruments measuring erythemally weighted solar irradiance, WMO/GAW 164 (World Meteorological Organization, Geneva) 1-50, 2006.

2.4 Polysulphone dosimetry

Polysulphone (PS) dosimetry is widely accepted as a reliable and useful technique in the assessment of personal UV exposure (Diffey, 1989; Kimlin, 2003). The spectral

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response of polysulphone is similar to the erythemal action spectrum (Diffey, 1984). This methodology is suitable to quantify the erythemally effective UV dose received by an anatomical site (the incident erythemally weighted irradiance on an anatomical site over a specified period of time, in Jm-2, hereafter called personal dose or exposure on a specific anatomical site). This polymer, when exposed to UV radiation, increases its optical absorbancy in the UV range. The change in PS film absorbancy (DeltaA) at 330 nm (post-pre exposure), depends on the effective dose absorbed by the dosimeter. PS dosimetry requires a careful determination of the calibration curve. This curve is obtained by exposing the PS dosimeters on horizontal plane at specific time intervals and simultaneously by measuring the ambient UV dose using a calibrated instrument (broad-band radiometer or spectroradiometer). The curve can be parameterized by a coefficient, c, multiplying a cubic polynomial function (Diffey, 1984; Diffey, 1989):

D= c(DeltaA+DeltaAˆ2+9DeltaAˆ3) (1)

where D (personal dose) is expressed in kJm-2.

This curve can be determined in situ or it can be derived once total ozone and solar zenith angle are known to take into account the local environmental conditions of the site (Casale et al., 2006). Three sites at different altitude were chosen in order to investigate on the variability of PS calibration curves: the lowest site of Saint Christophe, at Les Grange and at La Thuile-Les Suches ski field. At each site a series of dosimeters (from the same batch of those used during the field campaigns) were exposed on a horizontal plane to solar UV radiation from 10:00 to 16:00 LT in order to cover the entire range of solar zenith angles which can be viewed from the dosimeter worn by the volunteer. Dosimeters were removed at specific time intervals and at the same time UV dose rates were measured by the nearby broad band radiometer. The absorbance changes versus the corresponding ambient UV doses provided the calibration curve at that site. The uncertainty associated with doses, estimated by equation 1, depends on random errors, because systematic uncertainties are removed when dosimeters have the same thickness (in this case 40micrometers thick) and belong to the same batch

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(Diffey, 1989). The uncertainty on D was estimated to be +/-10% as derived from the error propagation formula taking into account an uncertainty of 0.001 on DeltaA (Diffey, 1989).

Casale, G.R., M. Borra, A. Colosimo, M. Colucci, A. Militello, A.M. Siani, R. Sisto: Variability among polysulphone calibration curves, Phys. Med. Biol. 51, 4413-4427, 2006.

Diffey, B. L.: Ultraviolet Radiation dosimetry with polysulphone film. Radiation Measurement in Photobiology, London Academic Press 135-159, 1989.

Diffey, B. L.: Personal Ultraviolet Radiation Dosimetry with Polysulphone Film Badges Photodermatol. 1, 151-157, 1984.

Kimlin, M. G.: Techniques for assessing human UV exposures. Proc. SPIE, Ultraviolet Ground and Space based measurements, models and effects III, San Diego A

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