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Personal UV exposure in high albedo alpine sites

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Abstract. Mountain sites experience enhanced UV radiation levels due to the concurrent effects of shorter radiation path-length, low aerosol load and high reflectivity of the snow surfaces. This study was encouraged by the possibility to collect original data of personal dose on a specific anatomical site (erythemally effective UV dose on the forehead) of two groups of volunteers (ski instructors and skiers) in the mountainous areas of Italy (the Alpine site of La Thuile-Les Suches in Valle d'Aosta region). Personal doses were assessed using polysulphone dosimetry. Exposure Ratio (ER), defined as the ratio between the personal dose and the corresponding ambient dose (i.e. erythemally weighted dose received by a horizontal surface) during the same exposure period was taken into account. In addition measuring skin colours as biological markers of individual response to UV exposure, was also carried out on the forearm and cheek of each volunteer before and after exposure.

The median ER, taking into account the whole sample, is 0.60 in winter, with a range of 0.29 to 1.46, and 1.02 in spring, ranging from 0.46 to 1.72. No differences in ERs were found between skiers and instructors in spring while in winter skiers experienced lower values.

Regarding skin colorimetric parameters the main result was that both skiers and instructors had on average significantly lower values of luminance after exposure i.e. they became darker. It was found that the use of sunscreen and individual skin photo-type did not produce significant variations in ER across instructor/skier group by day and by seasons ($p>0.05$). It seems that sunscreen use only at the beginning of the exposure or in a few cases a couple of times during exposure (at difference with the specific instructions sheets), was not sufficient to change significantly skin colorimetric parameters across participants.

In conclusion UV personal doses on the ski-fields are often significantly higher than those on horizontal surfaces and consistently more intense respect to personal doses received by sunbathers on the beach in central Italy (ER range: 0.09–0.42). Given the high levels of exposure observed in the present study, specific public health warnings with regards to 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.

1 Introduction

The amount of solar ultraviolet (UV) radiation at the Earth's surface depends on the incoming solar energy and the transmission properties of the atmosphere as well as the features of the site such as surface topography, orientation and albedo (Kerr, 2003). Solar UV radiation is known to have a significant impact on human health (skin and eyes are critical targets for UV exposure). Long term exposure is the major risk factor leading to premature skin aging, skin cancers (non-melanoma skin cancers, squamous and basal cell carcinoma, and melanoma) and cataract (McCarthy and Taylor, 2002; Norval et al.,2007; WHO, 2006). Acute effects consist in erythema (sunburn, i.e. cutaneous inflammatory reaction due to excessive solar UV exposure, Norval et al., 2007), photodermatoses, immunosuppression, phototoxicity/photoallergy and pigmentation (tanning) and in some eye pathologies (Diffey, 2004). On the other hand the synthesis

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of Vitamin D is the most beneficial effect on human health (Norval et al., 2007).

Mountain sites experience enhanced ambient UV radiation levels due to the concurrent effects of shorter radiation path-length, low aerosol load and high reflectivity of the snow surfaces. The Alps are one of the places where the highest values of UV levels in Europe are experienced (Meloni et al., 2000, Schmucki and Philipona, 2002, Seckmeyer et al., 2007) and tourism is leading more and more people onto ski fields with the result in skin damage due to UV overexposure of the body parts not usually protected by clothing such as nose, mouth, chin, cheeks and eyes.

Studies of UV radiation at high altitude sites have been carried out in Europe since the 1960s (Bener, 1960; Bener, 1963; Blumthaler and Ambach, 1988; Blumthaler et al., 1997; Schmucki and Philipona, 2002; Pfeifer et al., 2006) showing that highest UV irradiances occur due to synergic effect of the altitude and the reflection from snow and hence the upward radiation can be comparable with the incoming radiation. 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).

In general standard measurements of ground based UV radiation are related to horizontal surfaces (ambient irradiance) over a specified period of time (ambient dose) and carried out by well-calibrated instruments (spectroradiometers, broad-band and narrow-band radiometers). The quantification of UV exposure of human skin indeed requires measurements of erythemal doses (Parisi, 2005) on tilted surfaces. Only a few systematic UV measurements for differently oriented surfaces are available (Schauberger, 1990; Webb et al., 1999). Oppenrieder et al. (2003) developed and built a new automatic system to measure radiation fluxes in 27 positions at three different altitude sites in Germany in order to have quantitative UV data related to the directions of the oriented surfaces of human body in different environment conditions. Dosimetry is a technique used to quantify personal solar UV exposure of humans in different settings, during their ordinary activity. The most widely used UV dosimeters are polysulphone (PS) films which have a response to UV radiation similar to human skin (Diffey, 1989; Webb, 1999; Kimlin, 2003; Kimlin, 2005).

To our knowledge little is known about UV exposure of professional outdoor workers at high altitude sites and recreational alpinists who presumably receive the highest personal doses. Epidemiological studies showed that skiers are at an increased risk for the squamous cell carcinoma (Rosso et al., 1999). Furthermore PS dosimetry studies have not been carried out at high altitude sites so far. In Moehrle et al. (2000) and Moehrle et al. (2003), the occupational UV exposure of mountain guides and ski instructors in the Alps (2000) and only of mountain guides (2003) were assessed using *Bacillus subtilis* spore film dosimeters. They found that UV levels in these occupations exceed nine to 53 times the threshold limit value of 80 $\mathrm{Jm^{-2}}$ per 8-h work, using the CIE reference spectrum (1987) normalized at 298 nm. High UV exposure levels of professional ski instructors were measured using digital dosimeters at Vail, Colo, USA, (Rigel et al., 2003). Allen and Mckenzie (2005) measured the UV exposure at the Mount Hutt ski-field (2000 m a.s.l) in New Zealand and compared with the values measured at the same time in a nearby sea level site in Christchurch city using a single electronic dosimeter. They found that at the ski-field UV irradiances on horizontal surfaces were 20–30% greater than at the sea site; personal UV doses were significantly greater than those on horizontal surfaces. The same authors, in the second measurement campaign at Mt Hutt ski-field (2006) confirmed the overall results of their previous study. Antoine et al. (2007) assessed effective short term exposure among building workers in a mountain area at three different altitudes (500 m a.s.l., 1500 m a.s.l., 2500 m a.s.l.) in the South of Switzerland using spore film dosimeters on five body location. They found that personal measured doses between workers and between different body sites showed high variability due the local conditions and individual factors and ranged from 0 to 200% of ambient doses.

The general aim of our work was to assess personal UV dose using polysulphone dosimetry of two groups of skiers (ski instructors and skiers) at the Alpine ski field of La Thuile-Les Suches (2100 m a.s.l.) in Valle d'Aosta region (Italy). This region is located in the far north- west of Italy and it has the peculiarity that the territory is at an average height of 2000 m a.s.l. In addition, as in our previous study with sunbathers (Siani et al., 2008), a more specific aim was to measure colorimetric parameters before and after exposure on an exposed and on a non-exposed site. Colorimetric measurements were taken into account to evaluate UV pigmentation changes.

2 Materials and methods

2.1 Study location

A spring (30 March–4 April 2006) and a winter (29–30 January 2007) field campaigns were carried out at La Thuile-Les Suches ski field (45.7° N, 6.6° E, 2100 m a.s.l.) which has mostly ski slopes oriented towards east direction and chairlifts and ski-lifts, on the average, oriented towards northwest-west.

2.2 Study participants

Two skier groups were selected for this study: skiers were recruited among the staff of the ARPA Valle d'Aosta (Aosta Valley Regional Environmental Protection Agency) using an advertisement at the ARPA headquarter at Saint-Christophe (Aosta). Instructors were recruited voluntary at La Thuile ski school.

A total number of 62 adults (31 skiers and 31 instructors), aged 20–69 years participated in the campaigns. Some skiers as well as some instructors participated in multiple days in the spring campaign, some of them only in the spring or the winter campaign and some of volunteers participated in both campaigns. 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 photo-type of participants according to the classification of Fitzpatrick skin types (Fitzpatrick et al., 1974; WHO, 2006), before each field campaign.

In addition each participant was asked to complete a questionnaire about time intervals spent in the shade and indoor (Appendix A) at every PS change (approximately every 2 h). The participants were also asked about their sunscreen use at the beginning and at the end of their exposure.

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 (C.I.E., 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.

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, 569 m 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, 1640 m 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 s. 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 (Webb 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 as recommended by Seckmeyer et al., 2006. The ARPA spectroradiometer is intercompared with the travelling standard QASUME spectroradiometer (Gröbner et al., 2005) maintained at the PMOD/WRC (Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center, see http://www.pmodwrc.ch/euvc/euvc.html), every two years and is calibrated every month by an ARPA local operator by means of 200 W 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%.

2.4 Polysulphone dosimetry

For over 30 years it has been very well established that polysulphone (PS) UV dosimeters are the "gold standard" with respect to assessing personal UV exposures. (Diffey, 1989; Webb, 1995; Kimlin, 2003). A number of studies have also demonstrated an association between personal UV exposure (as assessed through sun exposure diaries) and personal UV exposures as measured with polysulphone dosimeters (Chodick et al., 2008). In the present study, however, we are not seeking to study the functioning of the polysulphone dosimeters with respect to performance rather with personal UV exposures with the ultimate aim to understand the links between exposures skin cancer incidence, progression and death in the population under study.

The spectral 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). The polysulphone is a polymer which increases its optical absorbancy in the UV range when exposed to UV radiation. The change in PS film absorbancy (ΔA) 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 a 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, 1989):

$$D = c\left(\Delta A + \Delta A^2 + 9\Delta A^3\right) \quad (1)$$

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, in order 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 the variability of PS calibration

Fig. 1. Instructor, dosimeter attached to the cap.

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 volunteers. 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 Eq. (1), depends on random errors, because systematic uncertainties are removed when dosimeters have the same thickness (in this case 40 mμ thick) and belong to the same batch (Diffey, 1989). The uncertainty on D was estimated to be $\pm$10% as derived from the error propagation formula taking into account an uncertainty of 0.001 on ΔA (Diffey, 1989).

2.5 Exposure Ratio

Exposure Ratio (ER) is defined as the ratio between the personal dose on a selected anatomical site (as defined in Sect. 2.4) and the corresponding ambient dose on a horizontal plane (as defined in Sect. 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:

$$\mathrm{ER} = \frac{\mathrm{Dose_{PS}}}{\mathrm{Dose_{Horiz.}}} = \frac{c\left(\Delta A + \Delta A^2 + 9\Delta A^3\right)_{\mathrm{PS}}}{\mathrm{Dose_{Horiz.}}} \qquad (2)$$

$\mathrm{Dose_{PS}}$ is the personal dose as measured by the PS dosimeter worn by the volunteers and retrieved from the calibration curve at the site. $\mathrm{Dose_{Horiz.}}$ is the corresponding ambient dose provided by the radiometer.

The overall uncertainty on ER was estimated to be $\pm$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%.

On the days of campaigns, each participant was equipped with a 40 μm-thick polysulphone (PS) film mounted in a plastic holder with a central hole of about 1 cm^2. We chose a vertically oriented dosimeter (a high UV-exposed site), attached to the cap (Fig. 1). Such vertical orientation can register both the incident UV radiation from the sun at moderately low solar elevation angles and UV radiation reflected from the snow. PS dosimeters were changed approximately every two hours in order to avoid saturation (10:00–12.00, 12:00–14:00, 14:00–16:00 LT (Local Time)) and ER was calculated for each time period.

Exposure Ratio was determined taking into account the ambient UV dose measured by the radiometer installed at La Thuile-Les Suches ski field. The altitude of 2100 a.s.l. was assumed as an average altitude of the ski field since the altitude range of ski slopes is 1700–2500 m a.s.l. Thus the c coefficient in Eq. (2) was determined from the calibration curve at that site.

2.6 Skin colour measurements

For each participant, measurements of skin colour on the forearm (constitutive pigmentation) and on an exposed site (the cheek), were carried out before and after the exposure using a Minolta spectrophotometer (model CM26000d). This instrument is based on physical measurement of reflected light, through an integrating sphere, at specific wavelengths (400–700 nm at 10 nm steps) which correspond to the spectrum of visible light. With this instrument it is possible to measure skin colour in the L^*, a^*, b^* system as defined by the Commission Internationale de l'Eclairage (C.I.E., 1976).

Colorimetric values are expressed in terms of: L^* (luminance) which gives the relative brightness on a scale from 0 (black) to 100 (white); a^* (redness) which represents the balance between red (positive value) and green (negative value) on a scale from +60 to –60; b^* (yellowness) measures the colour saturation between yellow (positive value) and blue (negative value) on a scale from +60 to –60. The Minolta spectrophotometer was used since it is recommended for the objective measurement of skin pigmentation and its changes (Park et al., 2002). Alaluf et al. (2002a) reported that there are, mostly with European subjects, close associations between a^* values and erythema or blood flow in the skin. Alaluf et al. (2002a, b) found that colorimetric parameters of human skin depend on the ethnic skin types. For the European: L^* ranges from 30–65 on photoprotected site to 30–54 for photoexposed site; a^* ranges from 4–7 on photoprotected site to 4–13 for photoexposed site; b^* ranges from 8–13 on photoprotected site to 8–19 for photoexposed site.

The traditional skin phototype classification (Fitzpatrick et al., 1974) is based on the observation of hair and eye colours, skin pigmentation, burning and tanning tendency. Colorimetric reading (L^*, a^*, b^*) shows a poor ability to correctly classify the intermediate phototypes II and III (Rubegni et al., 1997; WHO, 2006). In this study colorimetry measurements before and after exposure on an exposed and on a non-exposed site were taken into account only to evaluate UV-induced pigmentation changes. A pigmentation change was defined when a statistically significant difference in any of L^*, a^*, b^* was observed between pre and post UV exposure.

2.7 Statistical analysis

Data were analysed using the Statistical Package for Social Sciences (SPSS) software version 14.0. The median was used instead of the mean value as a statistical parameter when the values do not have a Gaussian distribution. The median is a measure of central tendency of a sample for which one-half (50%) of the observations lies above that value and one-half lies below that value. The Wilcoxon Signed Rank test, WSR (Wilcoxon, 1945) was used as a non-parametric alternative to the repeated measures t-test to check for differences within groups (skiers and instructors) of the measures of ER, $L^*a^*b^*$ and pre and post sun exposure. The Friedman test (Friedman, 1937) was used as a non-parametric alternative, two-way repeated measures analysis of variance by ranks, to detect differences in ER across multiple time slots (repeated measures), with the WSR to test for the specific differences between each couple of time slot. Statistical significance was set at $p \leq 0.05$ (two-tailed).

Table 1. Season group cross-tabulation. Count indicates the number of individuals participating in the campaigns. Individuals participated in both seasons are different from those participating in only one season.

Season		Group		Total
		Instructor	Skier	
Winter only	Count	6	7	13
	% within Group	19.4	22.6	21.0
Spring only	Count	19	11	30
	% within Group	61.3	35.5	48.4
Both seasons	Count	6	13	19
	% within Group	19.4	41.9	30.6
Total	Count	31	31	62
	% within Group	100.0	100.0	100.0
	% of Total	50.0	50.0	100.0

3 Results and discussion

3.1 Study participants

This study involved 62 participants (31 instructors and 31 skiers): 47 males and 15 females with a median age of 40 years ranging from 20 to 66 years. There were 11 and 4 females among skiers and instructors respectively. 33.9% (16 males and 5 females) of volunteers had skin Type II, (fair skinned Caucasians who burn easily and tan slowly and with difficulty) while 66.1% (31 males and 10 females) had skin Type III (medium skinned Caucasians who burn rarely and tan relatively easily).

A total number of 13 adults (6 instructors and 7 skiers) participated only in the winter campaign, 30 adults (19 instructors and 11 skiers) only in the spring campaign. There were indeed 19 participants (6 instructors and 13 skiers) in both seasons. A season group cross-tabulation is reported in Table 1.

Over the whole study period, 11 skiers and 14 instructors participated in one spring day, 13 skiers and 6 instructors in two spring days, 5 instructors in three spring days, 7 skiers and 6 instructors in one winter day. Taking into account both seasons, 9 skiers participated for a total of three study days (two days in spring and one in winter), 6 instructors and 4 skiers participated for a total of two study days.

All skiers wore three dosimeters which were changed approximately every two hours in both campaigns. Ten instructors used two dosimeters and only two instructors wore the third dosimeter in spring. In winter instructors wore only one dosimeter during the time slot from 10:00 to 12:00 LT.

In winter seventeen participants (11 skiers and 6 instructors) applied sunscreen once with sun-protection factor (SPF≤30) at the beginning of exposure. Only two instructors used very high SPF (≥50). In spring thirty participants (18 skiers and 12 instructors) applied sunscreen (SPF

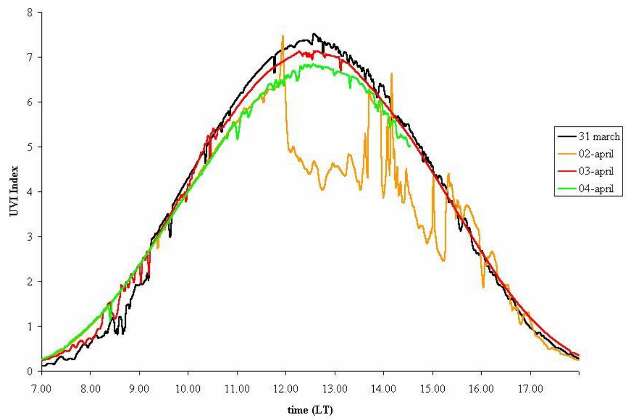

Fig. 2. UVI Index versus Local Time (LT) during the spring campaign

≤30) during the first time slot and seven re-applied sunscreen after noon. During both campaigns the participants performed their ordinary activity without affecting the use of PS dosimeters.

3.2 Ambient doses

In both campaigns ambient UV doses were recorded from 10:00 LT to 16:00 LT under almost clear sky conditions (1 April, not considered in the analysis, was completely cloudy while on 2 April scattered conditions occurred in the afternoon, but on this day the volunteers wore the dosimeters only in the first part of the day). Figure 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 25 m Wm^{-2} , Cost-713, 2000). In that period daily total ozone ranged from 330 DU to 369 DU and solar zenith angles (SZA) were 41°<SZA<54°. During the spring campaign the maximum UV index was 7.5. In winter a total ozone of 300 DU and 64°<SZA<70° were experienced and UV index peak was about 2. The monthly mean of UV indexes in those periods under clear sky conditions are 5.0 and 1.5 at Les Granges (45.7° N, 6.6° E, 1640 m a.s.l.) respectively (see http://www.uv-index.vda.it/). The data presented in the figure shows clearly the intense environmental UV radiation that the participants were exposed to at this site.

Assuming comparable environmental conditions within the 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.

3.3 Polysulphone dosimetry

Measurements of ambient doses for the calibration curve were carried out on 31 March. In that day the comparison among the ambient doses recorded at the three sites at different altitudes showed a percentage difference of 37.7%/1531 m (equivalent to 24%/1000 m) between La Thuile-Les-Suches and Saint Christophe and of 22.1%/1071 m (equivalent to 20%/1000 m) between Les Granges and Saint Christophe. It has to be noticed that the dependence of UV irradiance on altitude cannot be described by a single number because it depends on many parameters and it is a function of wavelength. The observed variability is not caused solely by the altitude but it depends on a combination of several factors such as Rayleigh scattering, clouds effects (not in this study), tropospheric ozone, 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. When a dedicated measurement campaign, in absence of snow but with similar total ozone amounts, was carried out during fall 2006, it was found that calibration curve was characterized by c values of (1.09±0.06) kJm^{-2} at Les Granges and of (0.96±0.03) kJm^{-2} at Saint Christophe. Both values resulted within the uncertainty associated to the Casale' values. This result shows that the snow contribution can be a prevalent factor with respect to the altitude in causing an increase of c value.

3.4 Exposure Ratio

In Table 2 Exposure Ratio results for the spring and winter campaigns at each PS dosimeter change (approximately every two hours) are reported in terms of median, minimum (min.) and maximum (max.) values. It can be seen that the behaviour of ER is not necessarily similar to the corresponding ambient doses (reported in Sect. 3.2). In fact, although Exposure Ratio is determined using ambient dose, it also depends on the personal dose which is influenced by individual factors such as time and the duration of exposure, body posture and orientation to the sun. It should be kept in mind that the limit of polysulphone dosimetry is that it does not allow to record individual personal doses differently from photoelectronic captors. The PS methodology requires a careful quantification of the calibration curve (ambient dose versus PS film absorbance changes prior and post exposure) nearby the site under investigation (Casale et al., 2006). Although somewhat variability was observed among the c values of calibration curves at the different altitude sites, an average

Table 2. Median, minimum and maximum Exposure Ratio (ER), at each PS dosimeter change approximately every two hours. ER_{10-12} (time period 10:00–12:00 LT); ER_{12-14} (time period: 12:00–14:00 LT); ER_{14-16} (time period: 14:00–16:00). Significance level for the Wilcoxon Signed Rank test, WSR, is 0.05.

		Winter				Spring			
Group		Age	ER_{10-12}	ER_{12-14}	ER_{14-16}	Age	ER_{10-12}	ER_{12-14}	ER_{14-16}
Instructor	Median	44	.96	–	–	49	.79	.96	1.08
	Minimum	20	.29	–	–	21	.46	.51	1.00
	Maximum	66	1.46	–	–	66	1.72	1.3	1.16
Skier	Median	40	.59	.41	.69	40	.96	1.04	1.21
	Minimum	25	.40	.25	.19	25	.32	.75	.65
	Maximum	62	.85	.55	1.02	62	1.33	1.75	1.52
Significance WSR			< 0.001	–	–		0.274	0.123	0.764

altitude of 2100 m a.s.l. of the ski field for ambient dose and also for the calibration curve was assumed.

Due to the lack of information on specific altitude during skiing, it was not possible to analyse the altitude dependency of ER. Personal doses should tend to increase with altitude and with combined factors (Rayleigh scattering, a smaller amount of tropospheric gases and albedo) and, consequently, an increase of ER could be observed. Nevertheless at the same time individual body posture, repetitive movements during the activity, individual positions related to the sun, can be also responsible of high variability of ER. The dose received by the specific anatomical location (in this study the forehead) also depends on the activity index i.e. the proportion of time spent in the sun. This suggests that observed lower ER values could be related to longer time spent indoor and in shade. On the other hand low personal doses can be also found depending on the postural activity.

The first aim of the statistical analysis was to look for the differences (if any) between instructors and skiers. In spring ER increased in both groups from the median value of ER_{10-12} (time period: 10:00–12:00 LT) of 0.96 (min.: 0.32; max.: 1.33) for skiers and 0.79 (min.: 0.46; max.: 1.72) for instructors to ER_{14-16} (time period: 14:00–16:00 LT) of 1.21 (min: 0.65; max: 1.52) for skiers and of 1.08 (min: 1.00; max: 1.16) for instructors. There were no significant differences across the two groups in their median scores at each time slot (Table 2). Additionally, Friedman test showed weak significant differences in skiers across ER related to the three time slots (p=0.104). It was found that there were differences in skiers between ER_{10-12} and ER_{12-14} (p=0.021), as well as ER_{10-12} and ER_{14-16} although it did not reach statistical significance (p=0.055).

The highest median ER in the afternoon can be presumably due to exposure of the ski slopes in that time slot in which the reflected radiation can be comparable with the incident radiation.

In winter the median value of ER_{10-12} was 0.96 with a range of 0.29 and 1.46 for instructors. In contrast, skiers had a significant (p<0.001) lower value of ER_{10-12} (0.59 ranging from 0.40 to 0.85). Only for skiers, the ER of the three time periods differed from each other (p<0.001). There was a marked decrease in ER between time slots 10:00–12:00 and 12:00–14.00 as well as a significant increase between 12:00–14:00 and 14:00–16:00. The median of ER_{12-14} (0.41) was slightly decreased and in the afternoon (ER_{14-16}) the median was 0.69 (min.: 0.19, max.: 1.02). This may be due to the quasi-vertical orientation of the PS dosimeter which received less diffuse and reflected radiation when solar elevation was low in winter.

Results for winter and spring campaigns of Exposure Ratio (ER) averaged over the whole day, together with Exposure Ratio averaged over two winter days and four spring days, are summarized in Table 3. On day 5 only one skier participated and for this reason median, minimum and maximum values are identical. Within each group, in spring skiers received on average 105% of ambient dose (ranging from 63% to 137%) and instructors 87% of ambient dose (ranging from 46% to 172%), but this difference is not statistically significant (p=0.129). In winter the personal dose of instructors was on average 96% of ambient dose which is higher than skiers (54%). The higher winter values were probably due to the kind of activity of instructors in that period in which they mainly dealt with beginners and hence remained standing for long stretches of time.

Taking into account the overall total sample, the median value of ER in winter is 0.60, with a range of 0.29 to 1.46, and in spring 1.02, ranging from 0.46 to 1.72.

Looking at the differences across season we took into account only the 19 participants in both seasons and it was found that winter Exposure Ratio was 0.87 (min.: 0.29; max.: 1.46) and spring ER was 0.63 (min.: 0.46; max.: 1.22) for instructors while for skiers winter and spring ER were 0.54 (min.: 0.42; max.: 0.70) and 1.07 (min.: 0.81; max.: 1.32), respectively. There was not a seasonal significant difference

Table 3. Median, minimum and maximum Exposure Ratio (ER), averaged over each day of winter/ spring campaign and over winter 2 days and spring 4 days. Day 1=29 January 2007; Day 2=30 January 2007; Day 3=31 March 2006; Day 5=2 April 2006; Day 6=3 April 2006; Day 7=4 April 2006.

Group		ER averaged Day 1	ER averaged Day 2	ER averaged Winter 2 days	ER averaged Day 3	ER averaged Day 5	ER averaged Day 6	ER averaged Day 7 4 days	ER Spring
Instructor	Median		.96	.96	.77	.88	1.1	1.40	.87
	Minimum		.29	.29	.46	.59	.68	1.22	.46
	Maximum		1.46	1.46	1.2	1.34	1.25	1.72	1.72
Skier	Median	.54		.54	.85	1.29		1.23	1.05
	Minimum	.42		.42	.63	1.29		.92	.63
	Maximum	.70		.70	1.18	1.29		1.42	1.37
Total	Median	.54	.96	.60	.83	.95	1.10	1.25	1.02
	Minimum	.42	.29	.29	.46	.59	.68	.92	.46
	Maximum	.70	1.46	1.46	1.19	1.34	1.25	1.72	1.72

(p=0.463) within instructors although the number of instructors was small, while winter ER value is consistently lower (p=0.01) than spring ER within the group of skiers. This can be attributed to the fact that in winter most of ski slopes were in the shade (as derived from self-reported questionnaire).

The ER maximum values found in this study result to be higher than theoretical calculations performed by Koepke and Mech (2005). In that study they found an ER of 1.44 for a fixed tilted surface at 45° zenith angle, located at an altitude of 3000 m a.s.l., with a clear atmosphere without aerosol, with snow albedo of 0.9 and solar zenith angle of 60°. Although an exact comparison between the two results is not simple due to the different conditions and to the continuously changing postures of volunteers, a discussion on the discrepancy can be provided. The theoretical value is influenced by the direct beam as well as all sky diffuse radiation. The highest measured value is related to a vertically oriented dosimeter (the body location is the forehead) worn by volunteers skiing in a downhill direction mainly facing towards the sun. In this case the direct component may be comparable to Koepke's while the diffuse component includes also the contribution from the surface. In addition the reflected component plays a key role in almost doubling the value of ER at the site of the field campaign.

The use of sunscreen and individual photo-type did not seem to affect the skiing behaviour of participants showing no significant variations in ER across instructor/skier group by day and by seasons ($p>0.05$), differently from what reported in Bastuji-Garin and Diepgen (2002), who found that the use of sunscreens increased the duration of recreational sun exposure.

3.5 Colorimetric parameters

Looking at the differences between instructors and skiers on non exposed site (constitutive pigmentation), L^*, a^* and b^* on forearm in spring and winter campaigns were examined finding no differences across skiers and instructors in winter ($p>0.05$); in spring L^* on non exposed site was significantly (p=0.036) different between skiers and instructors. The latter had a lower value of L^* (i.e. darker) probably due to unintentional exposure of forearm during previous days.

The median values together with the minimum and maximum of L^*, a^*, b^* on the exposed site, pre and post exposure during spring and winter campaigns, for each ski group, are reported in Tables 4 and 5, respectively. Different values of L^*, a^* on the exposed site, both before and after exposure in both seasons ($p<0.001$) were found across skiers and instructors, while no difference resulted in the b^* parameter (p=0.089 in b^* pre exposure and p=0.250 in b^* post exposure). At difference with winter, instructors (pre and post exposure) were characterized in spring by lower median L^* and higher median a^* than skiers, probably due to the longer time spent outdoors during the previous months.

Both skiers and instructors had on average significantly lower median L^* and b^* after exposure (in spring and winter $p<0.001$). As expected, all subjects changed their skin pigmentation becoming darker after exposure. On the contrary a^* between post-exposure and pre exposure, did not differ in the median score (p=0.253 and p=0.06 in spring and in winter respectively).

When the analysis on post L^*, a^*, and b^* measures was carried out by sunscreen use, in winter no significant differences appeared among participants (instructors or skiers and by photo-type). In contrast, on 2 April (Day 5 of the spring campaign), those who used sunscreen (all had phototype III), experienced a post exposure higher L^* and lower

Table 4. Spring campaign: values of L^*, a^*, b^* pre and post exposure indicated as pre_exp and post_exp respectively.

Group		L^*_pre_exp	L^*_post_exp	a^*_pre_exp	a^*_post_exp	b^*_pre_exp	b^*_post_exp
Instructor	Median	48.76	48.00	15.38	14.84	15.89	15.07
	Minimum	37.84	41.22	10.58	12.50	11.40	11.81
	Maximum	59.12	58.11	18.19	17.73	20.63	19.36
Skier	Median	56.37	55.00	12.17	12.35	16.62	14.44
	Minimum	51.17	50.26	8.09	9.08	13.78	11.67
	Maximum	65.70	60.60	15.20	16.19	20.46	17.20
Total	Median	52.30	51.72	13.82	13.26	16.318	14.78
	Minimum	37.84	41.22	8.09	9.08	11.40	11.67
	Maximum	65.70	60.60	18.19	17.73	20.63	19.36

Table 5. Winter campaign: values of $L^*a^*b^*$ pre and post exposure, indicated as pre_exp and post_exp respectively.

Group		L^*_pre_exp	L^*_post_exp	a^*_pre_exp	a^*_post_exp	b^*_pre_exp	b^*_post_exp
Instructor	Median	59.33	57.22	13.38	15.22	16.84	14.99
	Minimum	53.61	50.91	10.08	10.84	14.41	12.26
	Maximum	67.28	64.28	17.58	20.74	20.02	17.19
Skier	Median	52.64	51.04	17.17	16.73	16.29	15.18
	Minimum	49.17	46.99	13.99	13.89	13.24	14.00
	Maximum	59.29	58.37	20.04	19.00	18.79	16.95
Total	Median	52.30	51.72	13.82	13.26	16.318	14.78
	Minimum	37.84	41.22	8.09	9.08	11.40	11.67
	Maximum	65.70	60.60	18.19	17.73	20.63	19.36

a^* (p=0.018 and p=0.011 respectively), as compared to no sunscreen users. Excluding Day 5, spring results did not differ from the winter results. Thus, it seems that sunscreen use at the beginning of exposure or in a few cases a twofold use, was not enough to change significantly skin colorimetric parameters. Only Day 5 showed a peculiarity.

The comparison between spring and winter parametric values carried out taking into account only participants in both seasons showed that L^* and a^* pre and post exposure in spring was significantly lower than winter values ($p<0.002$) while b^* pre and post exposure in spring was significantly higher.

4 Conclusions

High exposure to solar UV radiation is considered to be the most important environmental risk factor in the development of skin cancer, but quantification of human exposure as well as its baseline-reference is a complex issue (Knuschke et al., 2007).

This study was conducted to assess UV exposure in an environment of high ultraviolet light exposure, such as a mountainous site in the Alps (La Thuile – Les Suches in Valle d'Aosta). Exposure of skiers and ski instructors in two different periods (low and high UV index) was determined using polysulphone dosimetry which was for first time tested in such an environment. This methodology requires a careful quantification of the calibration curve under the same atmospheric conditions of exposure of the local population. It was found that the c value of calibration curves at different altitude sites was higher than those obtained theoretically under the same total ozone amounts and solar zenith angles.

New data in terms of Exposure Ratio (ER) for the Italian population were provided. In spring there are no significant differences within and between skiers and instructors. The median ER over all data is 1.02, ranging from 0.46 to 1.72. In winter instructors, due to posture during their ski lessons, received a higher dose than skiers (96% of ambient dose against 54% for skiers). The results of a pilot study in a population of Italian sunbathers showed that the exposed site (chest) received a personal dose ranging from the minimum of 9% of ambient dose for individuals mostly in motion and maximum of 41.7% for those mainly lying (Siani et al., 2008). Although a direct comparison is not possible, the major finding highlighted how exposure on ski-field resulted consistently higher.

The use of sunscreen does not seem to affect ER across instructor/skier group by day and by seasons and by phototype. With regards to colorimetric parameters, the main result was that both skiers and instructors had on average significantly lower values of L^* and b^* after exposure but the sunscreen use did not affect these values except in a spring day.

In conclusion the average personal UV exposure resulted being the same, and in some cases even more, than the ambient UV dose. This exceeds the values reported in WHO report (2006), ranging from 5% to 15% of total ambient UV radiation and for outdoor workers exposures can reach 20–30%.

The limitations of this study are that we could not estimate the cumulative personal doses of skiers and instructors, that requires a long time monitoring and that it is not possible to extend the results to the entire skiing population. However, this study may provide relevant information for the future health policies concerning sun-related behaviours (proper application and re-application of sunscreen and protective measures such as hats and sun glasses).

Appendix A

Questionnaire

Fill in the following questionnaire that will help us to interpret the results of the survey. Thank you

1) Date Name

2) The number of dosimeter you used:

3) Describe your activity during the time interval related to each dosimeter:

Time	At Sun	Partially sunny	Totally in the shadow	Standing	Skiing

4) Time spent indoor for each dosimeter

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References

Alaluf, S., Atkins, D., Barrett, K., Blount, M., Carter, N., and Heath, A.: The impact of epidermal melanin on objective measurements of human skin colour, Pigment. Cell. Res., 15, 119–126, 2002a.

Alaluf, S., Atkins, D., Barrett, K., Blount, M., Carter, N., and Heath, A.: Ethnic variation in melanin content and composition in photo exposed and photo protected human skin, Pigment. Cell. Res., 15, 112–118, 2002b.

Allen, M. and McKenzie, R. L.: Enhanced UV exposure on a skifield compared with exposures at sea level, Photochem. Phtobiol. Sci., 4, 429–437, 2005.

Allen, M. and McKenzie, R. L.: UV exposure on New Zealand skifields, in UV Radiation and its Effects: an update, Royal Society of New Zealand, Miscellaneous Series, 68, Wellington, 70–71, 2006.

Antoine, M., Sottas, P. E., Bulliard, J. L., and Venez, D.: Effective exposure to solar UV in building workers: influence of local and individual factors, J. Expo. Sci. Environ. Epidemiol., 17, 58–68, 2007.

Bastuji-Garin, S. and Diepgen, T. L:. Cutaneous malignant melanoma, sun exposure, and sunscreen use: epidemiological evidence, Br. J. Dermatol., 146(61), 24–30, 2002.

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 1590 m 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.

Blumthaler, M., Ambach, W., and Ellinger, R.: Increase in solar UV radiation with altitude, J. Photochem. Photobiol, B. Biol., 39,130–134, 1997.

Blumthaler, M. and Ambach, W.: Human solar ultraviolet radiant exposure in high mountains, Atmos. Environ, 22, 749–753, 1988.

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

Chodick, G., Kleinerman, R. A., Linet, M. S., Fears, T., Kwok, R. K., Kimlin, M. G., Alexander, B. H., and Freedman, D. M.: Agreement between diary records of time spent outdoors and personal ultraviolet radiation dose measurements, Photochem. Photobiol., 84(3), 713–718, 2008.

C.I.E. (Commission Internationale d'Eclairage): C.I.E. 1976 uniform color spaces, Colorimetry, C.I.E. publication, 15.2, 29–32, 1986.

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

COST-713 Action: UV Index for the Public. European, Communities, Brussels, 27, 2000.

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

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

Diffey, B. L.: Climate change, ozone depletion and the impact on ultraviolet exposure on human skin, Phys. Med. Biol., 49, R1–11, 2004.

Fitzpatrick, T. B., Pathak, M., and Parrish, J. A.: Protection of human skin against the effects of the sunburn ultraviolet (290–320 nm). Sunlight and Man: Normal and Abnormal Photobiologic Responses, edited by: Pathak ,M. A., Harber, L. C., Seiji, M., and Kukita, A.; consulting ed. T. B. Fitzpatrick, Tokyo: University of Tokyo Press, 751, 1974.

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.

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

Kerr, J. B.: Understanding the factors that affect surface UV radiation Proc. SPIE, Ultraviolet Ground and Space based measurements, models and effects III, San Diego August 2003, 5156, 1–14, 2003.

Kimlin, M. G.: Techniques for assessing human UV exposures. Proc. SPIE, Ultraviolet Ground and Space based measurements, models and effects III, San Diego August 2003, 5156, 197–206, 2003.

Kimlin, M. G.: Exposure to UV radiation and human health, Proc. SPIE, Ultraviolet Ground and Space based measurements, models and effects V, San Diego August 2005, 5886, N1–8, 2005.

Knuschke, P., Unverricht, I., and Ott, G.: Baseline – Reference of solar UV Exposures to assess individual UV exposure levels in the population, Proc. of the UV Conference, One Century of UV Radiation Research, Davos, Switzerland, Sept. 2007, 127–128, 2007.

Koepke, P. and Mech, M.: UV irradiance on arbitrarily oriented surfaces: variation with atmospheric and ground properties, Theor. Appl. Climatol. 81, 25–32, 2005

McCarthy, C. A. and Taylor, H. R.: A review of the epidemiological evidence linking ultraviolet radiation and cataract, Dev. Ophtalmol., 35, 21–21, 2002.

Meloni, D., Casale, G. R., Siani, A. M., Palmieri, S., and Cappellani, F.: UV dose patterns in Italy, Photochem. Photobiol., 71, 681–690, 2000.

Moehrle, M., Korn, M., and Garbe, C.: Bacillus subtillis spore film dosimeter in personal dosimetry for occupational solar ultraviolet exposure, Int. Arch. Environ. Health, 73, 575–580, 2000.

Moehrle, M., Dennenmoser, B., and Garbe, C.: Continuous Long-term monitoring of UV radiation in professional mountain guides reveals high exposure, Int. J. Cancer, 103, 775–778, 2003.

Norval, M., Cullen, A. P., de Gruijl, F. R., Longstreth, J., Takizawa, Y., Lucas, R. M., Noonan, F. P., and van der Leun, J. C.: The effects on human health from stratospheric ozone depletion and its interactions with climate change, Photochem. Photobiol. Sci., 6, 232–251, doi:10.1039/b700018a, 2007.

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

Oppenrieder, A., Hoeppe, P., Kopeke, P., Reuder, J., Seefeldner, M., and Rabus, D.: Measuring UV-radiation on inclined surfaces, Proc. SPIE, Ultraviolet Ground and Space based measurements, models and effects III, San Diego August 2003, 5156, 339–342, 2003.

Pfeifer, M. T., Koepke, P., and Reuder, J.: Effects of altitude and aerosol on UV radiation, J. Geophys. Res., 111, D01203, doi:10.1029/2005JD006444, 2006.

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

Park, S. B., Huh, C. H., Choe, Y. B., and Youn, J. I.: Time course of ultraviolet-induced skin reactions evaluated by two different reflectance spectrophotometers: DermaSpectrophotometer and Minolta spectrophotometer CM-2002, Photodermatol. Photoimmunol. Photomed., 18, 23–28, 2002.

Rigel, E. G., Lebwhohl, M. G., Rigel A. C., and Rigel, D. S.: Ultraviolet Radiation in Alpine Skiing, Arch. Dermatol., 39, 60–62, 2003.

Rubegni, P., Cevenini, G., Flori, M. L., Fimiani, M., Stanghellini, E., Molinu, A., Barbini, P., and Andreassi, L.: Relationship between skin color and sun exposure history: a statistical classification approach, Photochem. Photobiol., 65, 347–51, 1997.

Rosso, S., Joris, F., and Zanetti, R.: Risk of basal and squamous cell carcinoma of skin in Sion, Switzerland: a case – control study, Tumori, 85, 435–442, 1999.

Schauberger, G.: Model for the global irradiance of the solar biologically effective ultraviolet radiation on inclined surfaces, Photochem. Photobiol., 52(5), 1029–1031, 1990.

Schmucki, D. A. and Philipona, R.: Ultraviolet radiation in the Alps: the altitude effect, Opt. Eng. 41(12), 3090–3095, 2002.

Seckmeyer, G., Mayer, B., Bernhard, G., Erb, R., Albold, A., Jager, H., and Stockwell, W. R.: New maximum UV irradiance levels observed in Central Europe, Atmos. Environ., 31(18), 2971–2976, 1997.

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

Seckmeyer, G., Pissulla, D., Glandorf, M., et al.: Variability of UV irradiance in Europe, Photochem. Photobiol., 83, 1–8, 2007.

Siani, A. M., Casale, G. R., Sisto, R., Borra, M., Kimlin, M. G., Lang, C. A., and Colosimo, A.: Short-term UV exposure of sunbathers at a Mediterranean sea site, in print on Photochem. Photobiol, 2008.

Webb, A. R.: Measuring UV radiation: a discussion of dosimeter properties, uses and limitations, J. Photochem. Photobiol. B. Biol, 31 9–13, 1995.

Webb, A. R.: Solar UVB Instrumentation and Applications Amsterdam, Gordon and Breach Science Publishers, 1998.

Webb, A. R., Weihs, P., and Blumthaler, M.: Spectral UV irradiance on vertical surface: a case study, Photochem. Photobiol. 69(4), 464–470, 1999.

Webb, A. R., Gröbner, J., and Blumthaler, M.: A practical guide to operating broadband instruments measuring erythemally weighted irradiance, EUR 22595, ISBN 92-898-0032-1, Office for Official Publication of the European Communities, 2006.

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

World Meteorological Organization (WMO): Scientific Assessment of ozone Depletion: 2006, Report 50, Surface Ultraviolet Radiation: Past, Present, and Future, Chapter 7, 7.1–7.54, 2007.

World Health Organization (WHO): Environmental Burden of Disease Series, No. 13. Geneva: edited by: Prüss-Üstün, A., Zeeb, H., Mathers, C., Repacholi, M., 1–250, 2006.