Effect of snow albedo and topography on UV radiation

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Abstract. Erythemally weighted irradiance measurements from four Alpine sites were analysed with respect to surface albedo. During winter-time, UV irradiances at pristine alpine sites with extensive snow coverage can be on average 60% higher than lower-altitude sites. These UV enhancements are due to higher effective surface albedo and lower aerosol content. Significant tropospheric ozone absorption might also influence UV measurements at the urban site. Enhanced UV radiation from snow covered mountain slopes was inferred for the specific situation at Davos.

Introduction

Quality assured measurements of erythemal weighted solar UV irradiance from four Alpine sites in Austria and Switzerland were analysed for the period 2007 to 2009. The measurements were obtained with broadband filter radiometers and archived as 10 minute averages. The four sites are located at different heights above sea level and are within 80 km of each other. Table 1 summarises the main features of each site.

Table 1 Site information and peak UV and daily doses over the period 2007 to 2009. Doses are given in standard erythemal doses (SED), where 1 SED=100 Jm^{-2} erythemally weighted UV.

Site	Lat	Long	Altitude /m	Max UVI	Dose /SED
Innsbruck (AT)	47.26 N	11.38 E	577	8.1	52
Davos (CH)	46.80 N	9.83 E	1610	10.4	57
Hafelekar (AT)	47.31 N	11.39 E	2275	9.7	59
Weissfluhjoch (ch)	46.83 N	9.82 E	2540	10.8	60

Hafelekar is situated on the mountain top just above Innsbruck with a horizontal distance to the ground site in Innsbruck of less than 3 km. Similarly, Weissfluhjoch is located in a skiing area directly above Davos, with a horizontal distance to Davos of less than 2 km. Innsbruck is considered an urban environment with non negligible anthropogenic pollution from heating and car exhausts.

Relative differences to Innsbruck

The measurements from all sites were initially cloud-screened to obtain common cloud-free periods at all four sites. The remaining 85 days were analysed using morning measurements at 70 solar zenith angle (SZA) so that systematic effects due to changing solar elevations would not affect the interpretation of the results. The SZA was chosen because at the latitudes under study 70° is the lowest common solar elevation found during the whole year. Figure 1 shows the relative differences of each site to the lowest site Innsbruck for the cloud-free selections.

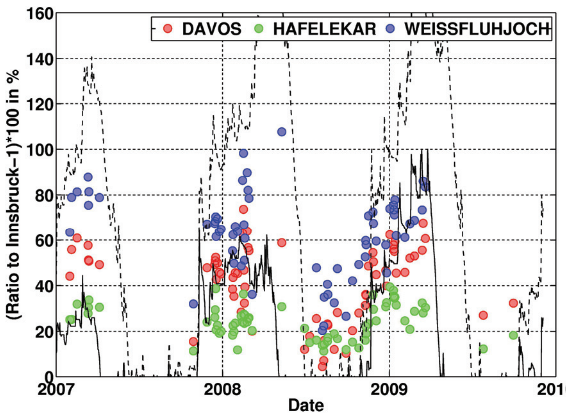

Figure 1. Relative differences in % of cloud-free erythemal weighted irradiances at 70 SZA relative to Innsbruck. The thick and dashed lines represent the snow height in cm at Davos and Weissfluhjoch respectively[1].

As can be seen in the figure, the relative differences between Innsbruck and the higher altitude sites are much larger in winter than in summer, reaching UV enhancements of 80 to 100% at Weissfluhjoch. Table 2 contains the average relative differences for the winter (December to February) and summer (June to August) periods.

Table 2 Average relative differences (%) of erythemal weighted irradiances at 70 SZA relative to Innsbruck, 577 m a.s.l. The winter period is defined from 1 December to 1 March and the summer period from 1 June to 31 August.

Site	Height difference /m	Summer	Winter
Davos	950	17%	46%
Hafelekar	1698	17%	28%
Weissfluhjoch	1963	36%	64%

As can be seen in Table 2, the altitude differences between the sites are not able to explain the large UV variations since the UV radiation in Davos, 1610 m a.s.l., is equal or higher than at Hafelekar, 2275 m a.s.l. even though the elevation of Hafelekar is much higher than Davos.

The UV enhancements observed at these locations in the European Alps can be put into the context of a case study performed between Mt. Hutt and Christchurch in

[1] Snow-height information was kindly provided by Dr. Christoph Marty, WSL SLF.

New Zealand; the observed UV enhancements on two days in Spring where 30% and 23 % for a height difference of 2050 m which are much lower than the corresponding values found in our study.

Effective surface albedo

The effective surface albedo represents the reflectivity of a homogeneous surface which produces the same downwelling UV irradiance as in the presence of an inhomogeneous surface. The effective albedo is used in one-dimensional radiative transfer models where the lower boundary condition (surface) is homogeneous.

In this study, the radiative transfer model uvspec was applied to the UV measurements of Davos to retrieve the effective surface albedo needed to reproduce the UV measurements. In addition to the cloud-free measurements, ancillary parameters such as total column ozone from a co-located Brewer and spectral aerosol optical depth from a precision filter radiometer (PFR) were used to constrain the model calculations. Figure 2 shows the effective surface albedo values retrieved for the period 2007 to 2009 for clear sky cases.

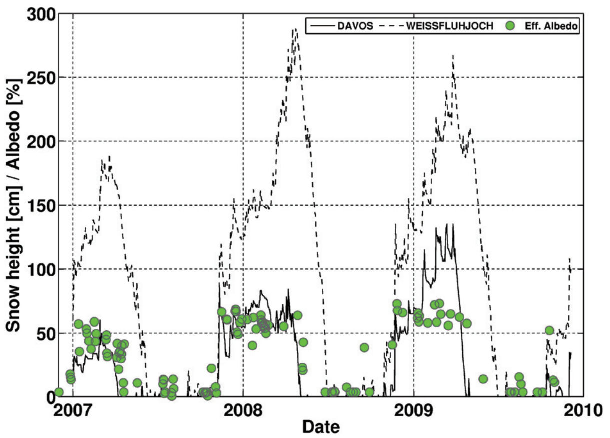

Figure 2. Effective surface albedo in % for Davos for cloud-free situations retrieved from radiative transfer calculations. Thick and dashed lines as in Figure 1.

The average surface albedo retrieved during the summer period is 0.06 with a standard deviation of 0.04, while in winter it is 0.57 with a standard deviation of 0.08. The summer values are consistent with essentially snow-free surroundings, while the winter values are very high due to the complete snow-cover at Davos and the surrounding area which is for the most part above the tree line. As can be seen in Figure 2, the effective surface albedo in Davos follows closely the snow height measured at Davos, dropping rapidly to summer values once the snow melts. Similar calculations were performed on a few selected days at Innsbruck assuming total column ozone values from a nearby station and aerosol characteristics of an urban city (measured AOD and assumed SSA of 0.9). Even though assuming a very low effective surface albedo of 0.1 in winter and 0.03 in summer, model calculations systematically overestimate the measurements by 7% and 5% in the summer and winter period respectively. The measurements and model calculations could be reconciled if the single scatter albedo is set to unrealistic low values. More likely would be the presence of about 10 to 15 DU of local tropospheric ozone which would reduce the modelled irradiances by about 3 to 5%.

Effect of topography

The influence of snow covered mountain slopes on UV irradiances measured in a valley was investigated at Davos by comparing the enhancement of UV radiation observed in winter with respect to the summer. At Davos, this enhancement due to snow covered surfaces is 29% at a fixed SZA of 70, while it is 25% at Weissfluhjoch which is situated above Davos close to the mountain top.

The local horizon at Davos obstructs 5.4% diffuse irradiance (assuming an isotropic diffuse UV radiation distribution), while at Weissfluhjoch this obstruction is negligible. The reflected UV radiation from the snow covered mountain slopes can be estimated to 4% by assuming a local snow reflectivity of 0.9, and a diffuse to global UV irradiance ratio of 0.85, which is in good agreement with the winter to summer UV enhancements seen between Davos and Weissfluhjoch.

Seasonal peak UV

Peak UV and daily doses were determined for the spring months at the European sites and compared to two New Zealand sites. While Innsbruck is lower or equal to Christchurch, all other mountain sites show substantially higher UV values due to the enhancements from the snow cover.

Table 3 Peak UV dose rates for February (August), March (September) and April (October) at four European and two New Zealand sites. Measurements from Mt. Hutt are from 13 September and 23 October 2003 only.

Site	Max UV-I			Dose /SED		
	Feb	Mar	Apr	Feb	Mar	Apr
Innsbruck	2.1	3.2	5.4	13	21	35
Davos	3.8	5.6	7.7	18	28	45
Hafelekar	2.8	4.4	6.2	16	28	44
Weissfluhj.	4.0	6.2	8.4	21	33	51
Christch.	2	4	6.5	11	20	35
Mt. Hutt	n/a	4.3	6.9	n/a	n/a	n/a

Conclusion

Erythemally weighted UV irradiances are found to be substantially higher in Davos and Weissfluhjoch with respect to Innsbruck and Hafelekar. While the much higher effective albedo in the Davos area is responsible for a major part of the observed radiation enhancement, substantial aerosol and possibly tropospheric ozone absorption is required at Innsbruck to explain the remaining differences between the sites.

In Spring, monthly peak UV dose rates observed in the pristine snow covered sites of Davos and Weissfluhjoch are found to be higher than for the corresponding months at Christchurch in New Zealand.

References

M. Allen, and R. McKenzie, Enhanced UV exposure on a ski-field compared with exposures at sea level, Photochem., Photobiol., Sci., 4, 429-437, 2005.