ERA-40 based daily UV surface albedo at 360 nm

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Summary

Daily values of UV surface albedo at 360 nm are provided for the period 01 Jan 1958 to 31 Aug 2002 and for each pixel of the COST-726 area. The available ERA-40 fields of water equivalent of snow depth in mm and of sea-ice fraction enable grid boxes to be identified, which are covered by snow, and / or (partly) by sea-ice. Furthermore, the snow age can be derived by the evolution of snow depth in the past days, and the snow depth in cm can be estimated using snow age dependent assumptions on the relation of water equivalent in mm and snow depth in cm. The albedo of snow and ice free pixels is set at the corresponding value of the daily FMI MTW UV surface albedo climatology. For parts of the COST-726 area monthly means of albedo for freshly fallen and for old snow can be derived from the MTW UV surface climatology and can be used in determining the current albedo. In case of snow at first the algorithm of Schwander is applied to calculate a regional albedo, which depends on snow depth and snow age and can vary between 19 and 50 %. In regions, monthly albedo means for freshly fallen snow and old snow are not defined, the albedo of the pixel is set at the regional albedo. In case the monthly albedo means are defined, the regional albedo related to its maximal possible difference is applied to scale between the albedo of freshly fallen and of old snow.

1 Introduction

The COST-Action 726 on “Long-term changes and climatology of UV radiation over Europe” schedules a reconstruction of past UV radiation, inter alia for a higher number of sites throughout Europe. The albedo of the soil generally is low in the UV (3-8 %) compared to that in the visible spectral range (Feister and Grewe, 1995). An essential exception is snow that also increases albedo dramatically in the UV, up to 96-98 % in Antarctica (Grenfell et al., 1994). Thus, for days the surface is not covered by snow, climatological values of UV surface will provide sufficient accuracy for modelling. However, modelling should account for variations in UV surface albedo due to snow and ice. Observed albedo from the sites, or auxiliary data like snow depth are not available in the COST-Action 726. J. Kaurola, Finnish Meteorological Institute (FMI) has retrieved daily data of snow depth and sea-ice from the archive of the ECMWF 40 year re-analysis (ERA-40) for the one degree grid used in COST-726. These data are applied to reconstruct increased UV surface albedo on a daily base, due to snow covered surfaces or sea-ice. For snow and ice free conditions the UV surface albedo is set at the value of the daily UV surface albedo climatology of FMI (Tanskanen, 2004). Following, the method is described, which has been used to generate the daily UV surface albedo database.

2 Input database

2.1 ERA-40 snow depth and sea-ice fraction

ERA-40 is a re-analysis of meteorological observations from September 1957 to August 2002 produced by the ECMWF. ERA-40 is based on the ECMWF data assimilation system and provides fields of a reduced Gaussian grid with a spatial resolution of about 125 km. The MARS archive post-processing software was used to interpolate the original fields to the regular 1 degree grid used in COST- 726 (31° N to 80° N, 25° W to 35° E, increment 1 degree in latitude and longitude).

The ERA-40 snow depth is given in mm of water equivalent (Kallberg et al. 2004). Glaciers have the set value of 10,000 mm, which has been reduced to 999 mm in the COST available data to save disk space. SYNOP observations include observations of snow depths. However, the availability of these parts of SYNOP has been limited to Canadian observations and from 1966 onwards to that of the former Soviet Union. Data from other countries could be used only from 1976 onwards (Uppala et al., 2005). In situ measurements of snow depth were analysed using the ECMWF successive correction method, with an adjustment applied that relaxed the analysis towards climatology in absence of measurements. Time series of global-mean snow mass has exhibited low values from 1992 to 1994 due to an error in the snow analysis (Uppala et al., 2005).

A validation of ERA-40 snow cover (Martin 2004) focussed on the French Alps uses the snow climatology calculated by the French analysis system SAFRAN coupled with the snow model CROCUS. When looking at the snow cover within the winter, the snow cover evolution is realistic, and the daily evolution is in most cases in agreement between ERA-40 and SAFRAN/CROCUS. Precipitation is quite well simulated when looking at the average on the region and on a monthly basis. The comparison results are less good when looking at individual stations (discrepancy between real and model orography). However, snowfall is strongly underestimated and the inter-annual variability seems also underestimated. ERA-40 snow cover simulations compare reasonably well with the SAFRAN/CROCUS climatology, despite the underestimation of snowfall.

Sea-ice in ERA-40 is given as fraction (0 – 1) of the grid box. Sea-ice cover (Rayner, 2002) was taken from the HadISST1 dataset of monthly values produced by the UK Met Office. It has been used up to November 1981. Thereafter, the weekly NOAA/NCEP 2D-Var dataset was used until 2001. Interpolation was used to produce daily values from each dataset.

The satellite-based data give a detailed picture of concentration variations within the ice edge in winter, but have problems in the summer (especially in the Arctic) through the effect of surface melting on the passive microwave retrievals. The chart-based data are detailed in areas of operational interest, but contain less information about the inner ice pack. Sea-ice fields from HadISST1 and the 2DVAR are sufficiently homogeneous to use in ERA-40 without the need for bias-adjustments (Rayner, 2002). The percentage of open water in grid boxes with partial sea ice cover is also quite consistent in the two data sets and not outside the general variability.

2.2 FMI MTW UV surface albedo climatology

The FMI has produced a Lambertian surface albedo climatology at 360 nm from TOMS data using the Moving Time-Window Technique (MTW) (Tanskanen, 2004, Tanskanen et al. 2003). It is based on the assumption that the reflectivity values within a certain time-window around the day of interest form a sample of the reflectivity distribution whose lower tail corresponds to the clear sky case. An estimate of the surface albedo is obtained by fitting a linear function to the lower tail of the cumulative distribution of the sample. The MTW algorithm was applied to the TOMS 360 nm Lambertian Equivalent Reflectivity (LER) time-series to construct daily surface albedo estimates for the Nimbus-7 period (1979 – 1992). Finally, the daily surface albedo climatology was constructed by averaging the resulting surface albedo estimates for these years. Compared to the TOMS minimum LER climatology (Herman and Celarier, 1997), the FMI MTW climatology shows higher surface albedo at high latitudes, especially in spring and autumn. In moderate and low latitudes the differences are relatively small.

The daily climatology can be downloaded via http://www.gse-promote.org. High latitude pixels of the climatology can show gaps for days of the winter season due to polar night or high solar zenith angles and thus UV radiances below the measuring threshold of the instrument. These gaps are closed by inter- and extrapolation. In case the gap is less than one month a time weighted albedo average of the both edge days is applied. Gaps lasting for more than a month are closed by determining the maximum albedo from of the two week periods edging the gap. This maximum albedo is set at the centre of the gap, and following it is linearly interpolated between the albedo of the centre day and the edge days.

3 Determining daily UV surface albedo

3.1 Regional snow albedo in the UV

High UV albedo, as measured in Antarctica (Grenfell et al., 1994, Bernard et al., 2006), is valid for a terrain, which can be assumed to be homogeneously covered with snow and ice. Such regions may be found in Antarctica, the Arctic Sea, the Arctic tundra, and the inland ice on Greenland. Outside the afore-mentioned areas a terrain homogeneously covered with snow does not occur. Snow-free areas can be trees, rocks, roads, roofs of buildings etc. since they often become snow free, even during periods with snow cover. Snow covered forest shades parts of the surrounding area and thus reduces the effective albedo. The albedo at a location is determined by a region with a radius that can exceed 20 km (Degünther et al., 1998). Schwander et al. (1999) developed an algorithm to determine the regional albedo in the UV:

$$\mathrm{albedo}[\%] = 40 + 0.172 \cdot \mathrm{H} - 3.61 \cdot \mathrm{N} \qquad (1)$$

H is the snow depth (cm) and constrained to 2 to 60 cm, i.e. snow depth higher than 60 cm are set at 60 cm. N is the snow age and is given as number of days since the last day with freshly fallen snow of at least 2 cm. It is constrained to 0 (current day) to 6 previous days and is more decisive for the regional UV albedo than snow depth. Thus, the regional UV albedo can vary between a minimum (RALB_n) of 18.7 % and a maximum of 50.3 %. The algorithm is validated to be a generic approach (Lapeta et al. 2001). It is in good accordance with the findings of Tanskanen and Manninen (2007), and with the measured albedo of 62 % for freshly fallen snow at Lauder, New Zealand (McKenzie et al., 1998). Snow patches, snow depths less than 2 cm, may modulate the albedo to vary between snow-free value assumed to be less than 12 % and RALB_n.

ERA-40 contains the snow depth as water equivalent in mm. The water equivalent is transformed to a snow depth in cm assuming a variation between 1cm for freshly fallen (dry) snow per 1 mm water equivalent and 0.4 cm for (old) snow ageing 5 and more days (Caspar 1962). The snow depth is accumulated by positive increments in water equivalent of at least 2 mm compared to the previous day. Thereby, the increment in cm decreases linearly from 1.0 to 0.4 cm with increasing snow age between 0 and 5 days.

3.2 Monthly climatological albedo of freshly fallen and old snow

The FMI MTW daily UV surface albedo climatology is applied to derive spatially varying albedo values for freshly fallen and old snow on a monthly base. For each pixel the monthly mean albedo and its variance is calculated from the database. From this variance it is possible to estimate the variance of the 1979 – 1992 population to roughly be represented by a factor 13 applied to the variance of the daily climatology. The albedo of freshly fallen snow is defined to be represented by the 95-percentile of the cumulative frequency distribution, that of old snow by the 5-percentile. The albedo values for freshly fallen and old snow are undefined, if the monthly maximum is less than RALB_n or the monthly average is less than 15 %. If the 5-percentile is less than RALB_n it is set at RALB_n. The distribution of the albedo can be extremely skewed and can show a strong kurtosis. To account for this behaviour, the cumulative distribution is based on the (incomplete cumulative) Beta function (Press et al. 1996). The required parameter a, and b of the Beta function are estimated based on calculated average, variance, maximum, and minimum albedo of the 1979 – 1992 population (http://www.itl.nist.gov/div898/handbook/eda/section3/eda366h.htm). Following, the 95- and 5-percentiles are allocated by bisection. Bisection does not converge within 100 steps of iteration, if one of the Beta parameters is ≤ 0.1. This occurs if the predominant part of the population is concentrated very close to one of the extremes. In this case the percentiles are set at the maximum and the minimum, respectively. If the 95-percentile exceeds an albedo of 95 %, it is set at 95 %.

Over the COST-726 area albedo values of freshly fallen snow higher 90 % are exclusively found over the inland ice on Greenland, the glaciers of Iceland, and of the Kola Peninsula. Higher values than the maximum in the regional albedo are observed over the sea ice region East off Greenland, and over the high altitude parts of the Scandinavian mountains. In the other regions - if defined - the albedo of freshly fallen and old snow remains in the range of the regional albedo, and thus supports the findings on seasonal snow covered regions. Year-long the albedo of freshly fallen and old snow is undefined for the Seas with exception of the sea-ice regions, for Southern and Western Europe, for Central Europe West of about 20°E with the exception of the Alps, and for lowland Scandinavia South of about 59°N. This is due to frequent snow free periods also in winter months.

3.3 Specifying daily UV surface albedo

The daily UV surface albedo of COST-726 is specified to be the albedo "snow-free", if the ERA-40 snow depth and the ERA-40 sea-ice fraction is zero. It is set to the regional albedo applying the algorithm of Schwander et al. (1999), if the snow depth calculated from the water equivalent of ERA-40 is ≥ 2cm and the albedo of freshly fallen snow is undefined. Otherwise, if the albedo of freshly fallen snow is defined, the result of the regional albedo minus RALB_n related to the maximal possible difference (50.3 % - 18.7 %) is applied to scale between the albedo of freshly fallen and of old snow. If the snow depth calculated from the water equivalent is less than 2 cm, the average of RALB_n and the albedo snow free is applied.

In case of sea-ice the fraction is used to scale between the albedo of sea-ice and that of open water. If sea-ice is covered by snow than the result of the aforementioned calculation is applied. If it is not covered by snow than the albedo of old snow is applied. In the case the latter is undefined, than the albedo of sea-ice is set at RALB_n.

Especially in case of sea-ice it is possible that the MTW climatology shows an albedo greater than 12 %, which is assumed to delimit between the albedo snow-free and an albedo of the grid box at least "corrupted" by snow patches. In this case the albedo snow-free is taken from the next summer-wards value of the pixel, which is snow-free. If this fails, it is set at the albedo of the next snow-free pixel equator-wards.

4 Results

The daily data of UV surface albedo for the periond 01 Jan 1958 to 31 Aug 2002 are accessible via the BSCW server. They are given as percent integers (i2); the data structure is in accordance with the other available ERA-40 products for the COST-726 area.

The daily UV surface albedo is constructed for all pixels of the COST-726 area and the period 1958 to 2002 based on the aforementioned method. Figure 1 gives the resulting frequency distribution. It shows a dominating peak between 3 and 7 %, which is related to the albedos snow-, ice-free of land and of sea surfaces. The secondary peak at 12 % is related to pixels with sub-pixel contamination due to snow or sea-ice. The tertiary peak at 19 % can be assigned to RALB_n. Above 19 % the albedo values are more or less equally distributed up to the maximum of the regional albedo, and on lower level up to about 75 %.

Figure 2 shows the strongly differing spatial distribution of UV surface albedo over Central Europe and parts of Western Europe at 08 March 1970, a winter with large snow depths also in the lowlands, and in contrast at 08 March 1989, a winter showing only few days with snow cover.

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References

Bernard G, Booth CR, Ehramjian JC, Nichol SE (2006): UV climatology at MacMurdo Station, Antarctica, based on version 2 data of the National Science Foundation's Ultraviolet Radiation Network. J Geophys Res 111, D11201: 1-15, doi: 10.1029/2005JD005857.

Caspar W (1962): Die Schneedecke in der Bundesrepublik Deutschland. Deutscher Wetterdienst - Zentralamt, Offenbach / Main, pp. 456.

Degünther M, Meerkötter R, Albold A, Seckmeyer G (1998): Case study on the influence of inhomogeneous surface albedo on UV irradiance. Geophys. Res. Letters 25: 3587-3590.

Feister U, Grewe R (1995): Spectral albedo measurements in the UV and visible region over different types of surfaces. Photochem. Photobiol., 62, No.4, 736 –744.

Grenfell TC, Warren SG, Mullen PC (1994): Reflection of solar radiation by the Antarctic snow surface at ultraviolet, visible, and near-infrared wavelengths. J. Geophys. Res. 99, No. D9, 18669 – 18684.

Herman JR, Celarier EA (1997): Earth surface reflectivity climatology at 340-380 nm from TOMS data, J. Geophys. Res., 102, 28003-28011.

Kallberg P, Simmons A, Uppal S, Fuentes M (2004): The ERA-40 Archive. ERA-40 Project Report Series No. 17, pp. 31.

Lapeta B, Schwander H, Koepke P (2001): Adaption of Radiative Transfer Modelling to Simulate UV Radiation on Top of a Mountain, in IRS 2000: Current Problems on Atmospheric Radiation, Deepack Publ. Hampton Virginia, pp. 373-376.

Martin E (2004): Validation of Alpine Snow in ERA-40. ECMWF ERA-40 Project Report Series, No.14, pp. 21.

McKenzie RL, Paulin KJ, Madronich S (1998): Effects of snow cover on UV irradiance and surface albedo: A case study. J Geophys Res 103 (D22): 28785-28792.

Pirazzini R (2004): Surface Albedo measurements over Antarctic sites in summer. J Geophys Res 109, D20118, pp.15, doi: 10.10129/2004JD004617.

Press HW, Teukolsky SA, Vetterling WT, Flannery BP (1996): Numerical Recipes in Fortran 77: The Art of Scientific Computing. Second Edition, Cambridge University Press.

Rayner N (2002): HadISST1 and the Reynolds et al. analysis. ECMWF ERA-40 Project Report Series, No. 3, pp. 169-176.

Schwander H, Mayer B, Ruggaber A, Albold A, Seckmeyer G, Koepke P (1999): Method to determine snow albedo values in the ultraviolet for radiative transfer modeling. Appl. Optics 38:3869-3875.

Tanskanen A, Arola A, Kujanpää J (2003): Use of the moving time-window technique to determine surface albedo from the TOMS reflectivity data, In: Proc. SPIE Vol. 4896, p. 239-250.

Tanskanen A (2004): Lambertian Surface Albedo Climatology at 360 nm from TOMS Data Using Moving Time-Window Technique. In: Proceedings of the XX Quadrennial Ozone Symposium, 1-8 June 2004, Kos, Greece.

Tanskanen A, Manninen T (2007): Effective UV surface albedo of seasonally snow-covered lands, Atmos. Chem. Phys., 7, 2759-2764.

Uppala SM, Kallberg PW, Simmons AJ, Andrae U, Da Costa Bechtold V, Fiorino M, Gibson JK, Haseler J, Hernandez A, Kelly GA, Li X, Onogi K, Saarinen S, Sokka N, Allan RP, Andersson E, Arpe K, Balmaseda MA, Beljaars ACM, Van De Berg L, Bidlot J, Bormann N, Caires S, Chevallier F, Dethof A, Dragosavac M, Fisher M, Fuentes M, Hagemann S, Holm E, Hoskins BJ, Isaksen L, Janssen PAEM, Jenne R, McNally AP, Mahfouf J-F, Morcrette J-J, Rayner NA, Saunders RW, Simon P, Sterl A, Trenberth KE, Untch A, Vasiljevic D, Viterbo P, Woollen J (2005): The ERA-40 re-ananlysis. Q. J. R. Meteorol. Soc. 131, 2961-3012, doi: 10.1256/qj.04.176.

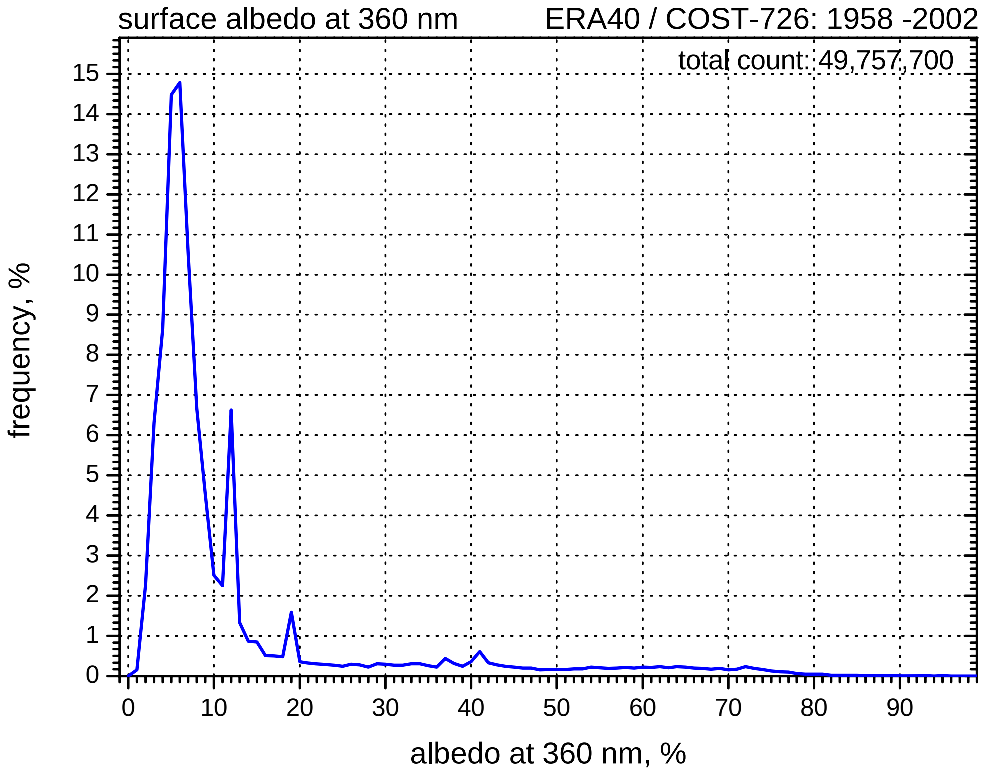
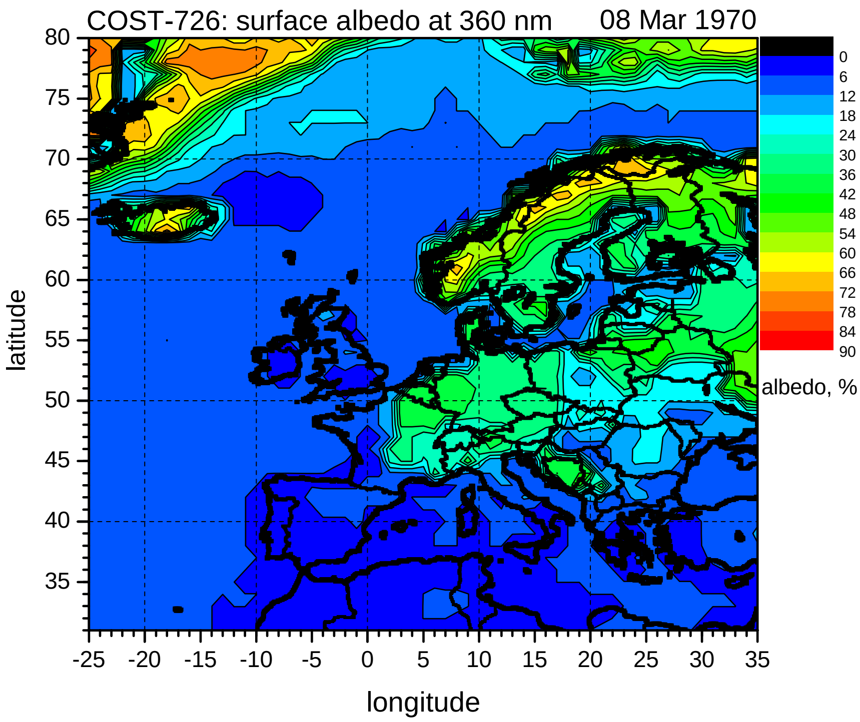


Figure 1. Frequency distribution of UV surface albedo: Total pixels of the COST-726 area, and period 01 Jan. 1958 to 31 Aug. 2002.



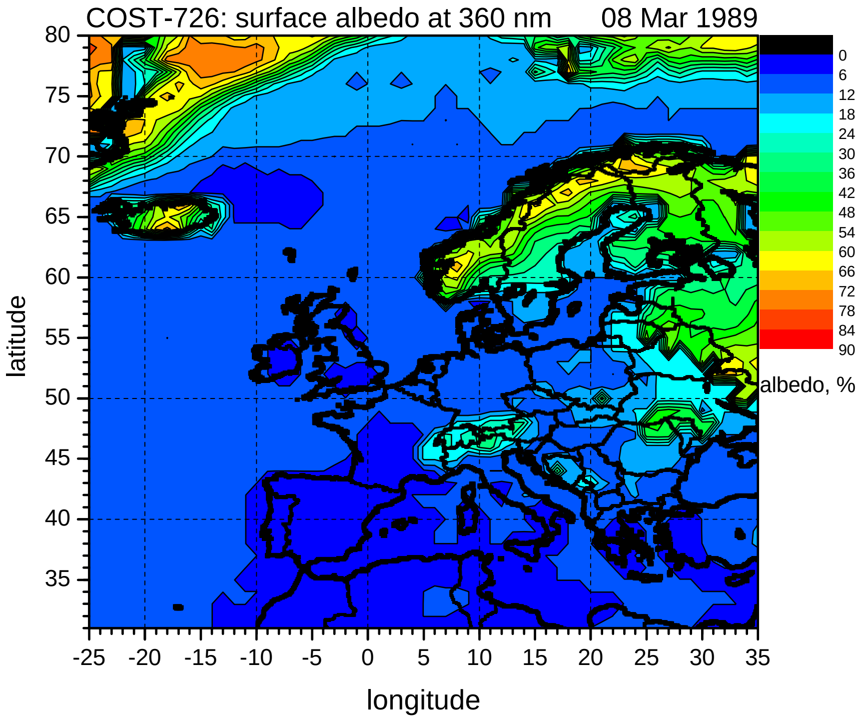


Figure 2. Spatial distribution of UV surface albedo: Top at 08 March 1970, bottom at 08 March 1989.