Investigation of the Effect of Contrails on Direct and Diffuse Irradiance

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Abstract. In the present study we investigate the effect of contrails on global shortwave radiation. This investigation is performed using continuous hemispherical fish eye photographs of the sky, diffuse and direct shortwave measurements. These measurements have been performed at the solar observatory Kanzelhöhe (1540 m.a.s.l) located in the southern part of Austria during a period of one and half year. The time resolution of the measurements is one minute, which allows to accurately follow the formation -eventually the disappearance or the movement - of the contrails in the sky. Using the fish eye photographs we identified clear sky days with a high contrail persistence. We especially look at situations where the contrails were obstructing the sun. First results show that contrails moving between sun and observer/sensor may reduce the global radiation by up to 68%. In general we however observe that during days with a high contrail persistence the diffuse irradiance is slightly increased. Finally a statistic of the contrail persistence during the period of measurement is presented. In addition the maximum and mean reduction in global irradiance are shown as a function of sun obstruction duration by contrails.

Keywords: Contrails, Global radiation.
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INTRODUCTION

There has been much research dealing with the effect of air traffic on climate. Most of the investigations have focused on the radiative forcing caused by contrails and by cirrus cloudiness formed from contrails. Most of these studies investigate this effect by using radiative transfer models and by using satellite information on contrail coverage, contrail optical thickness, man made cirrus cloudiness etc. The mean annual radiative forcing estimation for the specific location Herbstmonceux [1] is -0.5 W/m² in the shortwave wavelength range and 0.75 W/m² in the longwave wavelength range which leads to a total radiative forcing around 0.25 W/m². In general 85% of the days with persistent contrails are also days with cirrus cloudiness.

There are only few studies investigating the effect of contrails on ground-based irradiance by using ground-based measurements. Wendler et al. [2] performed a case study using fish eye photographs and ground-based measurements of direct and diffuse irradiance. They found maximum decrease in global irradiance of up to 16% (116 W/m²) when the contrails were moving between the sun and the observer. Between these obstruction events the diffuse irradiance was increased by up to 29%. This enhancement however also includes the effect of cirrus cloudiness. Feister and Shields [3] investigated the enhancement of diffuse irradiance solely by contrails and found enhancements around 8%. Pfister et al. [4] showed that there may be a short-term increase in global irradiance of up to 60% caused by thin clouds but on average over an hour the enhancement would not be larger than 10%. Altogether there are still only a few studies dealing with measurements of the effect of contrails on ground based diffuse and direct irradiance. The present study uses routine fish eye measurements and ground based global irradiance measurements to investigate the effect of contrails on shortwave global irradiance. Longwave irradiance is not considered.

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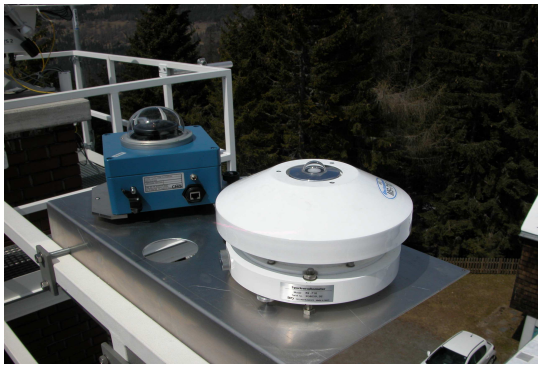


FIGURE 1. Fish eye camera (CMS Schreder) (on the left) which performs 1 minute routine photographs of the sky hemisphere with a 180 degree angle of view. On the right hand side an EKO MS 710 Spectrometer may be seen.

METHODS

These investigations were performed at Sun Observatory Kanzelhöhe, Carinthia, Austria which is situated at 1526 m altitude. Sun Observatory Kanzelhöhe is a station of the University of Graz which performs various meteorological measurements. Typical synoptic and climatic measurements are also being performed by the Austrian Weather Service. Sun Observatory Kanzelhöhe also hosts an Aeronet station. A high quality radiation station (BSRN level) is just being installed. Routine measurements of global irradiance with EMS 11 silicon photodetector pyranometers at 1-minute intervals have been performed since June 2010. In addition fish eye photographs of the sky hemisphere at 1-minute intervals with a 180 degree field of view automatic camera (CMS Schreder) (Figure 1) have been performed.

Using fish eye photographs, videos were created for each week. Using these videos, days with contrail persistence as well as the time of day when sun obstructions by contrails occurred were identified visually. A contrail is considered to be persistent when the contrail is still visible after the plane has disappeared. Within the scope of the present study we determine the reduction Rmax of the global irradiance during a sun obstruction event by a contrail:

$$Rmax = (I1+I2)/2 * Imin \quad (1)$$

where

I1 is the global irradiance before the sun obstruction which corresponds to time T1,
I2 is the global irradiance after the sun obstruction which corresponds to time T2,
Imin is the minimum global irradiance during the sun obstruction by the contrail.

We also determine the mean global irradiance Imean during the whole time in which the contrail is between the sun and observer (is equal to the mean of the global irradiance between T1 and T2). Using equation 1 and substituting Imin by Imean we may determine the mean reduction Rmean during a sun obstruction.

RESULTS

Case Study 22-23 September 2010

We analyzed two consecutive days (22-23 September 2010). September 22 was almost cloudless without any contrail persistence during the whole day. The diurnal range of global irradiance on this day shows a perfect bell shaped curve (Figure 2). September 23 was a day with a strong contrail persistence. All the sun obstruction events by contrails were identified and are shown in Figure 2 by arrows. Altogether 49 contrails could be observed, 22 of which moved between sun and observer. Reductions in global irradiance of up to 68% (370 W/m²) were observed. Between the sun obstruction events an enhancement of global irradiance compared to the day before may be seen. The comparison of the aerosol optical depths measured by Aeronet on 22 September and on 23 September showed similar values on both days and could not explain these radiation enhancements.

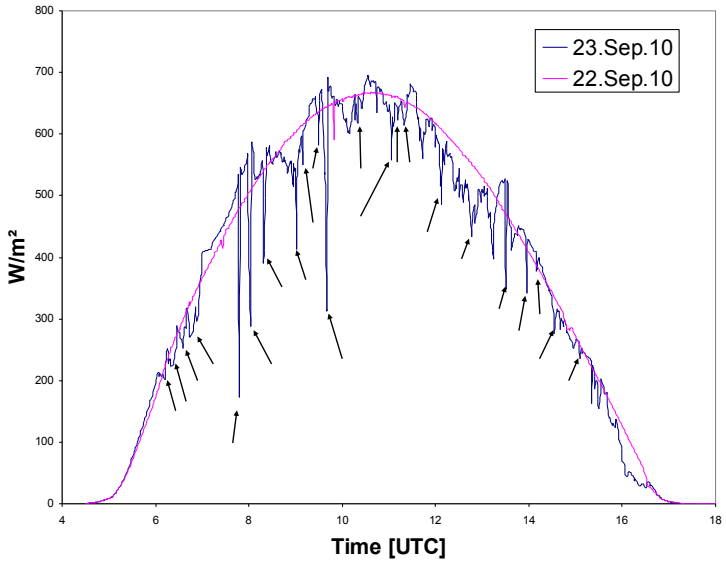


FIGURE 2. Global irradiance of two consecutive days: 22 and 23 September 2010. September 22 was a clear sky day without contrail persistence whereas on 23 September 2010 a strong contrail persistence (altogether 49 persistent contrails from 0600 to 1600 UTC) was observed. The arrows show the decrease in global irradiance due to contrails shading the sun (altogether 22 such events were observed).

Statistical Analysis

The number of persistent days during the months, September 2010, October 2010, November 2010, January 2011, February 2011, March 2011, May 2011 and June 2011 was determined (Figure 3). The maximum persistence was reached in January 2011 with approximately 35% of all the days showing contrail persistence. Altogether the persistence is larger during late Autumn, Winter and early Spring.

Besides persistence, Rmax and Rmean were determined for all sun obstruction events by contrails where any interference by cirrus clouds during the events could be omitted. The results for Rmin and Rmean are shown in Figure 4a and 4b respectively. The maximum Rmax is 68% which corresponds to a reduction in global irradiance of 370 W/m². The mean of all Rmax is equal to 16%. The mean of all Rmean is equal to 8%. The maximum duration of a sun obstruction event by a contrail is 15 minutes whereas the mean duration of a contrail remaining between sun and observer is 5 minutes.

To make any assessment as to any enhancement or reduction of hourly or daily radiation sums, the enhancement in global irradiance by contrails and cirrus cloudiness between the obstruction events needs to be estimated. We made the assumption that all cirrus cloudiness during contrail persistent days are man made. A preliminary estimation (using only two days) showed an average increase in global irradiance between the sun obstruction events - compared to a clear sky reference day - of around 8.3%.

CONCLUSION

If the rough number of 8.3% for the global irradiance enhancement is taken, the following statement may be made: The sun must be obstructed between 35 and 40 minutes per hour in order to obtain a reduction in global irradiance. This corresponds to approximately 7 to 8 contrails moving between the sun and observer. Altogether the strong decrease in global irradiance during a sun obstruction by a contrail shows that if air traffic frequency continues to increase a contrail frequency may be reached where the duration of sun obstruction by contrails reaches the threshold over which each additional contrail leads to a reduction in the daily global radiation sum compared to a clear sky reference day.

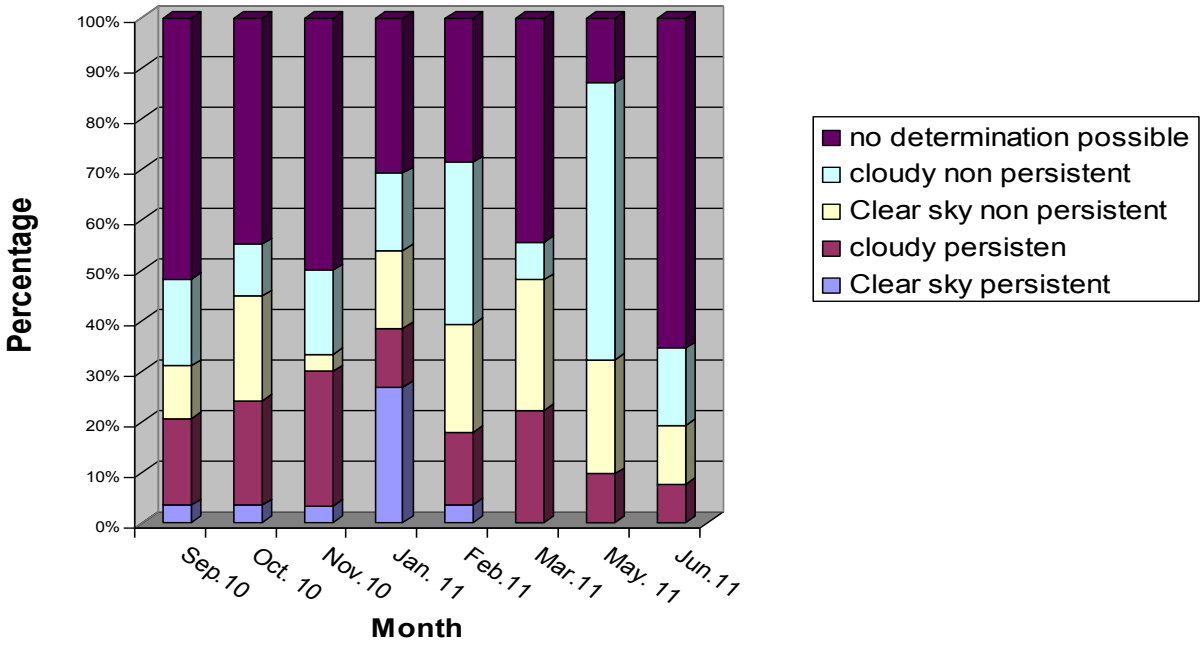
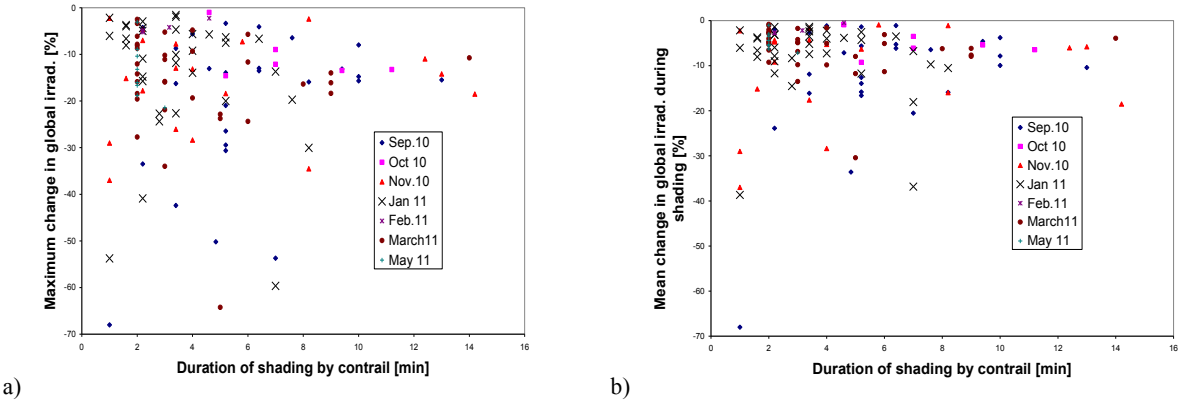


FIGURE 3. For each month the percentage of days with and without contrail persistence are shown. Many days (upper part of the columns) mostly with full cloud cover do not allow a determination as to the persistence of contrails. The green and yellow parts of the columns are clear sky and cloudy days without contrail persistence whereas the two lowest partitions of the columns show contrail persistence under cloudy and clear sky conditions.



a) b)

FIGURE 4. The maximum **a)** and mean **b)** reduction in global irradiance (during the shading event) as a function of the duration of the shading event by the contrails is shown for the 8 months that were analysed. For June 2011 no shading event was suited for the analysis because of interfering cloudiness which falsified the global irradiance decrease.

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