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Atmospheric Measurement Techniques
Discussions

Interactive comment on "Potential impact of contrails on solar energy gain" *by* P. Weihs et al.

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We would first like to thank the reviewer for the comments which helped to substantially improve the quality of the present manuscript:

Here follow the detailed answers to the comments:

R.1) REVIEWER comment: "The paper covers a technique to examine the impacts of contrails on the energy loss associated with typical photovoltaic arrays used in the solar energy industry. The technique was laid out pretty clearly and plainly. My one concern lies in the discrimination between contrail and cloud. The authors point out that persistent contrail, by their definition,tend to occur in cloudy skies. What is not clear to me is how cloudy? Is there some measure of cloud fraction that could be provided?"

"This also makes me wonder if cloud fraction was considered as a criteria in the data selection, if even visibly? This could make a difference in the strength of this assumption."

"The assumption stated in lines 7-9 on page 8931 would benefit from a calculation or citation to back up this choice. I appreciate the clear statement of the assumption, but something to back it up would help."

A.1) AUTHORS response:

We calculated the cloud fraction during the investigated cases using the software findclouds by Schreder company. For 90% of the selected time periods the cloud fraction was equal or below 2/10, for 10% the cloud fraction was above 2/10.

Uncertainties in the determination of the effect of contrails on global radiation (Rmax) may arise from

1) changes in direct irradiance caused by other clouds before, during and after an obstruction event by contrails

2) changes in diffuse irradiance before, during and after the obstruction event due to other clouds

ad 1) Changes in direct irradiance: Only cases without any other visible clouds (except contrails) close or in front of the sun before, during and after the obstruction event were selected for our study. Only sub visual clouds could therefore have an influence on the Rmax determination accuracy. This uncertainty was estimated based on sub visual cloud optical depth values of Cadet et al.(2003) using a RT model. We obtained maximum changes in irradiance of up to 2%.

ad 2) Changes in diffuse and global irradiance by sub visual and thin cirrus clouds before, during and after the obstruction event:

Cases with clouds close to the sun (where the largest reflexion by clouds may occur) were omitted. According to our measurements an increase in diffuse irradince caused by reflexions by other surrounding clouds would lead to an increase in global irradiance of up to approximately 8%. This is also the maximum uncertainty which could result from the effect of clouds on diffuse irradiance.

CHANGES IN THE MANUSCRIPT:

Following sentence was now removed: " We assume that other clouds in the sky (e.g.sub visual or visual cirrus clouds, or small cumulus clouds) have an impact on global radiation lower than 1% during the sun obstruction events. "

We changed following sections in the methods chapter, which now read like this:

". If the creation of the contrails could not be seen, the identification of the contrails was made based on their typical linear shape. In case of doubt, when the clear identification between contrails and other wave shaped cirrus clouds (e.g. cirrus fibratus, radiatus or vertrebatus) was not possible or when other clouds were moving close to the sun, the case was omitted......"

"Within the scope of the present investigation we determined the reduction Rmax of the global irradiance during a sun obstruction event by a contrail as:

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

Where

I1 is the global irradiance before the sun obstruction (clear sky reference) which corresponds to time T1

I2 is the global irradiance after the sun obstruction (clear sky reference) which corresponds to time T2

Imin is the minimum global irradiance during the sun obstruction by the contrail

In order to calculate the enhancement and reductions of global radiation by contrails

and clouds - for the same time and day - a reference clear sky global radiation needed to be calculated. Calculations of global radiation were therefore performed using the radiative transfer (RT) model interface uvspec from the LIBRADTRAN (Mayer and Kylling, 2005) package. Calculations were performed using SDISORT with two streams and SBDART molecular absorption approach. In order to compensate for small discrepancies between RT model calculations and measurements of global radiation due to uncertainties in model input parameter determinations (e.g. sub visual cirrus clouds) or expected systematic measurement errors of $\pm$ 2%, the RT model calculations were first compared with the measured global radiation of cloudless (0 tenth cloud fraction) time periods of the same day or of the next partly cloudless day taking aerosol optical depth and solar position into account. The model results were fitted to the measured global radiation by introducing a correction factor in the order of maximum 1.05 or 0.95 (correction of 5% of the model values).

Uncertainties in the determination of Rmax (see eq. 1) may arise from fluctuations of the direct beam during the obstruction event or from fluctuations of the diffuse irradiance before during and after the obstruction event. Since we only selected cases without other clouds - except the contrails - close or in front of the sun, only sub visual clouds could therefore obstruct the direct beam at the same time than the contrails and lead to uncertainties in the determination of the global irradiance changes caused by contrails.

We assumed a maximum optical depth of the sub visual clouds of 0.03 according to Cadet et al. (2003), and simulated the uncertainty caused by sub visual clouds by using the RT model interface uvspec. Maximum changes of the direct beam irradiance of 2% and of global irradiance of up to 1.7% - which represent at the same time one uncertainty of the determination of the effect of contrails - were obtained.

The second uncertainty mentioned above pertains to a changing diffuse irradiance before during and after the obstruction event (not related to radiation reflected by contrails close to the sun). This may occur when larger clouds would move close to the sun (these cases were already removed) or for larger or changing cloud fractions before and after the obstruction event. Using the findcloud software (CMS Schreder) the cloud fraction during the selected cases was therefore determined: during 90 percent of the cases the cloud fraction was equal or below 2 tenths. 10 percent of the cases only showed larger cloud fractions. During time periods with larger cloud fractions, surrounding clouds (not close to the sun) may however lead to enhancements in global radiation of up to 8% (see section 4). This uncertainty could add to the uncertainties related to sub visual clouds and model correction factors already mentioned above.

R.2 REVIEWER comment: "With enough of a lower cloud layer, higher level clouds could be masked with a visible analysis. This could impact the assumption made about the reduction due to other clouds. Please see the related comment below as well as a couple of other minor details."

A.2) AUTHORS response: As mentioned above, only cases without any other visible clouds (except contrails) close or in front of the sun, before, during and after the obstruction event were selected for our study.

R.3) REVIEWER: Minor comments p. 8929, line 14: Repeated "at"

A. 3) AUTHORS: Sentence was changed to "... performed the measurements with intervals of at least 1 minute"

R 4) REVIEWER: p. 8936, line 8-11: I found this sentence is a bit awkward.

A.4) AUTHORS response: Sentence changed to: "With a further increase in air traffic a threshold may be reached which automatically leads to reductions of daily solar energy yield on days with contrail persistence."

Interactive comment on Atmos. Meas. Tech. Discuss., 7, 8927, 2014.