

Dear editor

In the following you will find all our answers to the referee comments. The marked-up manuscript is attached at the end of this file.

We believe that the suggestions and comments of the Referees have substantially helped to improve the paper and we hope that the manuscript, which required minor revision, is acceptable for publication in *Atmospheric Measurement Techniques*.

Kind regards

Christine Aebi

## Reply to comments by J. Calbó (Referee #1)

on the manuscript " Long-term study of cloud radiative effect, cloud fraction and cloud type at two stations in Switzerland using hemispherical sky cameras " by Aebi et al., submitted to *Atmospheric Measurement Techniques*.

We thank the referee for the constructive comments that we have tried to accommodate in the text. Detailed answers to the comments are given below (bold: referee comment, regular font: author's response).

This paper presents a summary of radiation measurements performed at two sites in Switzerland, in combination with estimations of cloud cover and type based upon an automatic method performed on whole sky images. Specifically, radiation measurements are presented as cloud radiative effect, as the corresponding modelled irradiances for a cloudless sky are subtracted from measurements. Although the literature on cloud radiative effect is pretty large, there is still room for more studies that add insight on this matter, specially for observational studies from ground-based measurements. So this study is worth to be published, although a number of issues should be addressed before publication. I must say that in general I enjoyed reading the manuscript and that all my comments below are provided with the intention of further improving this study.

General comments:

- (1) Cloud radiative effects are computed by subtracting model estimations of cloudless sky shortwave and longwave irradiances from the corresponding measurements. Therefore, the performance of the "cloudless" models is critical to get suitable values of CRE. The authors give the mean bias of models for both sites, but I suggest that more detail about the performance of cloudless sky models is shown in the paper. It should be quite easy, just by showing the CRE computed for cases corresponding to 0 octas. This could be shown as function of SZA (for shortwave) or as function of month or temperature (for longwave). If the models were correct, the CRE for these cases should be 0 (or at least, centered at 0). If there is a systematic bias at either of the sites, for some SZA, etc., this could be used to further discuss the results. You should also clarify if the "clear sky cases" that you use to assess the models are the same that are later defined as "cloud-free" cases.

Thanks for this comment. The Figure here show in different panels the mean SCE\_rel depending on SZA (left) and the mean LCE depending on the screen-level temperature (right) for the cloud-free cases in Davos (top row) and Payerne (bottom row). For the shortwave we see that there is a slight increase in the uncertainty with higher SZA.

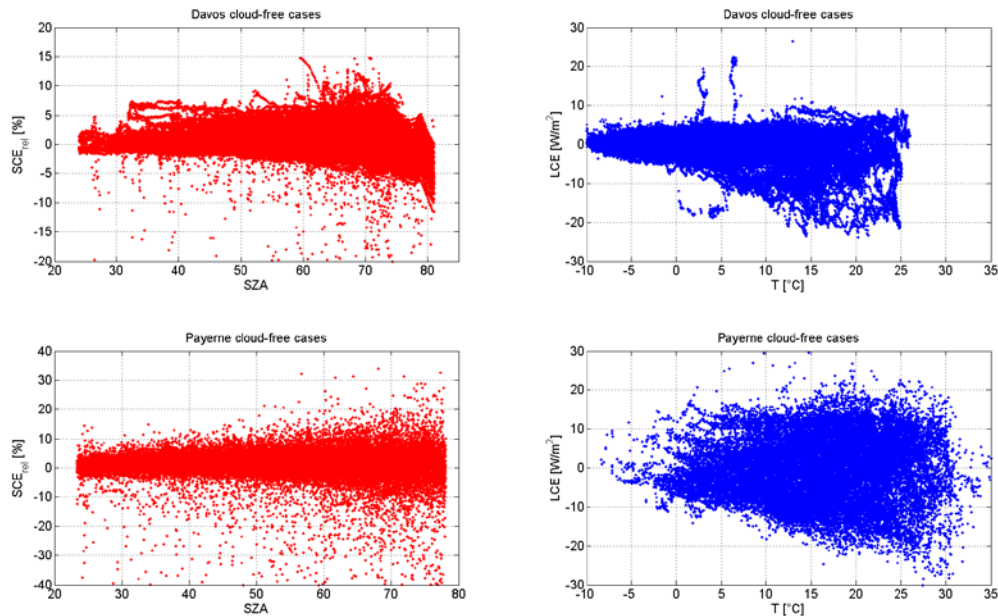
We decided to not include this Figure in the paper. However for the shortwave we calculated the mean and the standard deviation separately for  $SZA < 50^\circ$  and  $SZA > 50^\circ$  and added these values in the text:

p. 4, l. 31 and p.5, l. 1-4:

The difference between SW measurement and the cloud-free model depends on the SZA. The bigger the SZA, the higher the mean difference. In Davos, the mean difference changes

from  $7.2 \pm 20.7 \text{ Wm}^{-2}$  ( $0.9 \pm 2.6 \%$ ) for data with  $\text{SZA} < 50^\circ$  to  $5.7 \pm 14.7 \text{ Wm}^{-2}$  ( $1.1 \pm 3.8 \%$ ) for data with  $\text{SZA} > 50^\circ$ . In Payerne, the mean difference is  $7.3 \pm 41.7 \text{ Wm}^{-2}$  ( $1.0 \pm 5.2 \%$ ) for data with  $\text{SZA} < 50^\circ$ . The mean difference is with  $3.3 \pm 34.1 \text{ Wm}^{-2}$  ( $0.6 \pm 8.9 \%$ ) slightly larger for data with  $\text{SZA}$  from 50 to  $78^\circ$ .

Thanks also for the comment about the clear-sky and cloud-free cases. We changed now everything to cloud-free.



- (2) Some deeper discussion of results is needed. In particular, there are some important differences between the two sites, and some strange behavior of CRE that should be highlighted and commented. The authors already make some comments, but additional insight would be appreciated. For example, regarding cloud type (figure 2), there are almost no Cu (and very few St-As) at Payerne, while there are almost no Cb-Ns at Davos. Or, Table 2 shows, for St-As class, that while in Davos enhancements (i.e. CRE > 0) are found for  $cc < 5$ , in Payerne CRE reaches very low values (CRE < -35%). It is particularly strange the value for  $cc = 1$ , as the median is equal to the first and third quartile (-70%). This also affects results in Table 3, where the behavior at Davos and Payerne is strangely different, in particular for  $cc < 5$  and for most cloud type classes. I wonder if this might be the result of a bias in the cloudless irradiance estimation at one of the two sites (see my previous point) or also a consequence of a very limited number of cases for some particular conditions of  $cc$  and cloud type. I mean, for statistics to be somewhat representative, a minimum number of instances should be included; moreover, a number of instances corresponding to different seasons, years, etc., would be convenient.

We added some more paragraphs to discuss the different behavior in the data following your suggestions:

p. 7, l. 6ff.:

In Davos, as determined by our algorithm, from October to May St-As is 5 present in at least 40 % of the cases per month. This fraction of St-As is rather too high and might be due to a limitation of the cloud type algorithm. The limitation is, that the algorithm applied for Davos is trained with images from Payerne. Therefore it might be more difficult to distinguish between low-level cloud classes (e.g. St-As and Sc) in Davos. This limitation might also be responsible for the rather infrequent determination of Cu in Davos.

p. 12, l. 5ff.:

For the calculation of the values in Table 2 different numbers of cases have been taken into account (see Table A1 and A2). Analysing e.g. the images that belong to the group St-As and 2 oktas in more detail, leads to the result that at all the images for this specific group in Payerne the sun is covered by a cloud, whereas in Davos, of the 58 images only in around 20 % of the cases the sun is occulted and in the remaining 80 % the sun is visible. As further discussed in Section 3.3.2, this fact of visible or occulted sun can lead to a large difference in  $SCE_{rel}$  values. These larger differences in  $SCE_{rel}$  values between the two stations mainly occur when only a limited number of images is available. Therefore, some of the  $SCE_{rel}$  values have to be taken with caution.

Additionally we added in the appendix two tables (A1 and A2) which show the number of cases that have been taken into account for the calculation of Table 1, Table 2 and Table 3.

#### Specific comments:

- (1) **Title.** I don't think the word "long-term" reflects the content of the study, which is performed on 3-4 years of observations. In fact, no further attention is put on the length of the time series, so simply removing "long-term" from the title would be adequate.

We changed the title to:

Cloud radiative effect, cloud fraction and cloud type at two stations in Switzerland using hemispherical sky cameras.

- (2) **Abstract.** OK in general. You could add that CBH is from ceilometer and IWV from GPS measurements. You could simplify the writing when referring to occulted (measured direct radiation less than  $120 \text{ Wm}^{-2}$ ) or visible Sun (direct radiation greater than  $120 \text{ Wm}^{-2}$ ).

The following sentence has been added in the abstract:

p. 1, l. 3-4:

The cloud base height (CBH) information are retrieved from a ceilometer and integrated water vapour (IWV) data from GPS measurements.

As suggested, the two terms occulted and visible sun have been added and are used in the following:

p. 1, l. 9-11:

In cases where the measured direct radiation value is below the threshold of  $120 \text{ Wm}^{-2}$  (occulted sun) the  $\text{SCE}_{\text{rel}}$  decreases substantially, while cases where the measured direct radiation value is larger than  $120 \text{ Wm}^{-2}$  (visible sun) lead to a  $\text{SCE}_{\text{rel}}$  of around 0 %.

- (3) **2.2 SCE\_CSM is not a radiative effect, as you correctly state when defining this symbol. Therefore, I wouldn't use SCE\_CSM, but something as SW\_CSM, to avoid possible confusion.**

We changed the symbol SCE\_CSM to DSR\_cfm in Equation 2 and thereafter also in the text:

p. 4, l. 11:

$$\text{SCE}_{\text{rel}} = \text{SCE}/\text{DSR}_{\text{cfm}} * 100\%$$

- (4) **2.3. Clear sky models. If aerosol conditions are used in the SW model, the source of aerosol measurements/data should be explained in section 2.1.**

In Section 2.1, p. 3, l. 20-21, we already have the sentence:

Aerosol optical depth data are retrieved from precision filter radiometers (PFR, manufactured by PMOD/WRC).

However, to be more clear, we added:

p. 3, l. 20-21:

Aerosol optical depth (AOD) data, used for the shortwave cloud-free model, are retrieved from precision filter radiometers (PFR, manufactured by PMOD/WRC).

- (5) **2.4. Cloud fraction and cloud type. If I understand correctly, LCE is also part of the algorithm for cloud type recognition. Although this may be good for obtaining good classification results, it is quite strange in the frame of the present study, as in this way, the "dependent" variable to be studied (LCE) takes also part in the definition of one of the "independent" variables (cloud type). In other words, some "circularity" is introduced by using LCE as a feature for cloud type discrimination. This could partly explain why dispersion of LCE values depending on cloud type/cover is much lower than dispersion of SCE values.**

LCE as a feature in the cloud type detection algorithm has been added in order to better distinguish between low and high level clouds in cases the sky is fully covered. To add the LCE in the algorithm is an advantage, because in fully covered sky images, the textural features do not give enough specific information to distinguish between different cloud levels and therefore cloud types. Thus it would be too difficult to distinguish between different cloud types which would result in many misclassified images. Since LCE values are quite distinct for low and high level clouds, it helps to distinguish the different cloud levels.

- (6) **3.1.1. LW cloud effect. Could you at least speculate a reason for the non-linearity shown in Fig. 3?**

We added the sentences:

p. 8f, l. 11ff:

Clouds at different zenith angles in the sky have a stronger or weaker impact on the downward longwave radiation measured at the surface. In case the zenith angles of the clouds are not equally distributed in our analysed time period, this might be a reason for this nonlinearity in LCE. However, we have not analysed it in more detail yet and is subject of a future study.

- (7) 3.1.2. SW cloud effect. The first sentence could be set between parentheses within the current second sentence. I would recall some times that “higher” means “less negative”. In fact, in the third paragraph, where you say “For Payerne, a clearly lower...” I think it should say “higher”. In general, the use of relative values is “risky”, as for large SZA the SW irradiance may take very low values, so (given the unavoidable uncertainties in both measurements and cloudless estimations) the relative SCE\_rel may tend to very large values. I would suggest using a maximum SZA (SZA < 80 deg?) for the cases included in the analyses. Maybe the horizon characteristics of the two sites already limit the range of SZA, but this should be explicitly commented in the text.

We tried to make it more clear that for the SCE\_rel higher means less negative.

We decreased the maximum SZA for Davos and we specified the SZA ranges taken in section 2.1, p. 3, l. 25ff.:

Data have only been taken into account for daytime measurements when the sun is located minimum five degrees above the horizon and the mountains. For Payerne, the study of CRE includes data from January 1, 2013 to April 30, 2017 with a time resolution of five minutes. Data considered are during daytime with a solar zenith angle (SZA) of maximum 78°.

- (8) 3.2.1, Figure 5. I wonder if it is necessary to show results for Cu and Sc, as these results are almost undistinguishable. In addition, it doesn't make sense to put a CBH of 5 km for a low cloud; maybe results for 0.5 km up to 2.5 km for only one cloud type would be more adequate. In any case, the similar behavior between Cu and Sc might be the result of similar microphysical characteristics, not similar “shape”.

With Figure 6 (we guess that you meant this one), we want to show the influence of IWV on the LCE in general and not for a specific case or station. Thus, we think that this graph shows nicely this influence.

We changed the sentence as suggested (p.16, l. 10-11):

Cu and Sc show a similar behaviour in the model which might be explained by similar microphysical characteristics of the two cloud types.

- (9) 3.2.1, Figure 6. I think that the black line corresponds to 10 km and above, not to above 12 km as written in the text. It would be nice adding another panel, where the LCE is shown, for the 8 octas cases (i.e., for cc > 0.95), against CBH, and also distinguishing by ranges of IWV. I would say that this could be a quite interesting plot that would complement current Fig. 5 and 6.

We decided to remove the current Figure 7 and put a new one which shows the dependence of LCE on cloud base height for Payerne and linear regression lines of the following measured IWV ranges.

- (10) Figure 7 is very interesting, but it is showing that the median value of SCE<sub>rel</sub> for a given cloud clover might not very representative of what is happening, since in fact there are two very different effects (reduction and enhancement) depending on whether the Sun is occulted or not. Although you comment these two effects, it should be mentioned that median values in tables 2 and 3 are to be taken with caution.

We mentioned now that the median values in Table 2 have to be taken with caution (p. 12, l. 10-11). The reason why we still think that it makes sense to calculate the median with all data (reduction and enhancement) is, that e.g. in weather prediction models the input about clouds is an average over a certain time period where also enhancements and reductions occur.

- (11) Conclusions. As a general comment, I would suggest shortening a little bit this section, by removing some repetitive statements and non-essential results. In fact, most general statements correspond to well-known facts (e.g., "...cloud base height and fractional cloud coverage have an influence on the range of the LCE..."). When writing this kind of well-known results, it should be stated that the current study is confirming them. In other words, it should be made clearer what it is really a finding of the current study, and what are expected results and known facts that the study is confirming.

We have shortened and changed a large fraction of the conclusion.

## Reply to comments by Anonymous Referee #2

on the manuscript " Long-term study of cloud radiative effect, cloud fraction and cloud type at two stations in Switzerland using hemispherical sky cameras " by Aebi et al., submitted to *Atmospheric Measurement Techniques*.

We thank the referee for the constructive comments that we have tried to accommodate in the text. Detailed answers to the comments are given below (bold: referee comment, regular font: author's response).

**This study deals with the analysis of the cloud radiative effect in Switzerland using two sky camera systems in Davos and Payerne in conjunction with pyranometers, pyrgeometers and precision filter radiometers. The results provide analytical information about the shortwave, longwave and total cloud effect components, while a sensitivity analysis was performed as well.**

**The overall analysis is sound and after the following minor revisions it could be published in the AMT journal.**

- (1) **First of all there is a confusion with the Tables throughout the paper. On page 7, line 26 the authors present the LCE results, so the correct Table is 1 (and not 2). Subsequently, on page 10, line 5 Table 3 need to be replaced with Table 2 (describes the SCE), while on page 12, line 10 the corresponding Table is 3 and not 4 (there is not even such a Table in the manuscript).**

We acknowledge your comment on that, it was a compilation error and the table numbers are in the right order now.

- (2) **On page 4, line 19 it is recommended to add an abbreviation for the "lookup table" as LUT in brackets (LUT) and then replace all the subsequent identical expressions with the "LUT" (e.g. on page 4, line 22; 24; etc).**

We added the suggested abbreviation LUT and used it then throughout the whole manuscript.

- (3) **Finally, in Sections 3.2.1 (page 13, line 5) and 3.2.2 (page 15, line 2) it is preferable to mention and use as reference the corresponding sections instead of figures, unless Figures 3 and 4 describe the entirety of Sections 3.1.1 and 3.1.2.**

We changed the reference to the corresponding sections (instead of the reference to the figures).



## Reply to comments by Anonymous Referee #3

on the manuscript " Long-term study of cloud radiative effect, cloud fraction and cloud type at two stations in Switzerland using hemispherical sky cameras " by Aebi et al., submitted to *Atmospheric Measurement Techniques*.

We thank the referee for the constructive comments that we have tried to accommodate in the text. Detailed answers to the comments are given below (bold: referee comment, regular font: author's response).

### General comments:

- (1) The manuscript presents calculations of the cloud radiative effect for different cloud types and cloudiness at two stations in Switzerland. Cloud cover and cloud type have been determined using hemispherical sky cameras. Sensitivity analysis have been conducted to study the impact of integrated water vapor and cloud base height on the long-wave cloud radiative effect (LCE), and the occultation of the sun by clouds on the short-wave cloud radiative effect (SCE).

Clouds are the principal modulator of the radiation budget but remain the largest uncertainty in the estimates of the Earth's changing energy budget. Therefore, such studies are highly important and relevant in order to quantify the effects of clouds on the radiation budget and to monitor their long-terms changes. In addition, the study demonstrates the current limitations of such automated cloud observing systems and hence serve as a base for future improvements. Indeed, the lack of cloud observations at the surface is an important cause for the uncertainties related to clouds.

The manuscript is well structured and - with some exceptions - clearly written. The literature has been carefully selected and cited. Graphics and tables are clear and the captions self-explanatory. There are some issues with the used language. In particular the conclusions could be improved. When the focus is sharpened towards a more original, better structured and formulated conclusion, and some additional minor revisions will be included, this work will be a very interesting and valuable contribution to the atmospheric science community and is in my opinion absolutely suited for publication in AMT.

We appreciate your comments. The conclusion has been shortened and partially rewritten.

### Specific comments:

- (2) **Abstract:** The abstract should point to the most relevant results. LCE and SCErel for low-level clouds and 8 oktas cloud cover are described but no statement about the corresponding TCE is given which gives a quantitative feeling to the reader regarding the overall impact of clouds on the radiation balance. I propose to include the corresponding numbers, for instance in line 3 "The total radiative effect of low-level clouds at 8 oktas cloud coverage has a median value....The median of the corresponding long-wave cloud effect (LCE) is....For mid- and high-level clouds the TCE and LCE are significantly lower ..."

Indeed, the total cloud radiative effect (TCE) has not been included in the abstract so far. Following your suggestion we added the following sentence about the TCE on p. 1, l. 13-14:

The calculated median total cloud radiative effect (TCE) values are negative for almost all cloud classes and cloud coverages.

- (3) I see one main reason - apart from the atmospheric parameters - for the substantial spread in the CRE data, particularly in the LCE (e.g., Fig. 3 and Fig.5): The deficiencies in the cloud type classification algorithm itself such as misclassification, and/or the fact that only one cloud type can be determined even if several different cloud classes occur. It is for instance not reasonable why there are almost no Cu and St-As at Payerne and no Cb-Ns at Davos (see Fig. 2). In addition, it is unlikely that such low LCE values can occur for low level clouds (e.g., Sc, Cu, Cb-Ns) and high cloudiness (> 6 oktas) as indicated in Fig. 3. Similarly in Fig.5, it is unlikely, that LCE below 50 (40)  $Wm^{-2}$  occur for IWV contents < 15 (20) mm (see Fig 6, model calculations). So, it is very likely that all these data points are potential misclassifications. These issues should be addressed in the respective paragraphs (there is only a short statement on p. 13) and in the conclusions. Finally, could you derive from your dataset/figures/model calculations a rough percentage of misclassified cases?

The misclassification of images indeed leads to an uncertainty in the results. This problem has been added at several places throughout the whole manuscript (e.g. p. 10, l. 4).

The uncertainty of the cloud type classification algorithm has been given on p. 6 l. 5ff.

- (4) Conclusions: The conclusions should be shortened and better structured. The listing of well-known issues and repetitions should be avoided (e.g., "Different cloud types have differing effects on the radiation.." or the two sentences on p. 16/17 lines 25/5 and p.17 line 14 have a similar meaning (in case the first sentence refers to differences between the two stations and the latter to the differences between cloud types, it would be helpful to state the sentences at least in the same paragraph. Otherwise, the reader will be confused). Finally, the repetitive use of words and expressions such as "Our measurements/data show/It has been shown" should be minimized). Generally, only the most important results and their implications should be stated. In addition to the described results, I would also clearly state the deficiencies in the cloud type classification algorithm which lead to the large spread in the data, particularly in the LCE (see my previous comments). In fact, the authors do mention this issue in the conclusions but the paragraph appears somehow isolated. In addition, a statement about the methodology how the cloud type classification could be improved would be useful in the conclusions: Is it possible to improve the current cloud classification algorithms (and if yes how) or would it rather be a new algorithm by combining various observing systems/methods which measure/calculate the relevant parameters described in this manuscript (e.g., ceilometer for cloud base height, sky camera for cloud cover, LCE and SCE (i.e. observations and the corresponding cloud-free calculations of longwave and shortwave radiation), solar radiation data for the determination of the occultation of the sun and IWV)? Could the authors comment on these issues?

We have shortened and rewritten the conclusion and outlook part.

Technical corrections: some of the spelling and grammatical errors:

- (1) Use "cloud-free" instead of "clear-sky" throughout the manuscript ("clear-sky" refers to a sky without clouds and a low aerosol load. The latter is not necessarily the case, particularly at a

site in the Midlands such as Payerne. In addition, this is a study about the effect of clouds and thus I would use here rather the term "cloud-free" instead of "clear-sky").

Throughout the manuscript we changed all the terms clear-sky to cloud-free.

- (2) Use "oktas" instead of "octas" throughout the manuscript

Done

- (3) Use "longwave/shortwave wavelength range" instead of "longwave/shortwave wavelength region" throughout the manuscript

Done

- (4) p.2, line 18: "wider" instead of "broader"

Done

- (5) p.2, lines 19-21: You may rephrase this sentence, something like: "However, the temporal resolution of satellite products is limited. From the Meteosat Second Generation (MSG) geostationary satellites, for instance, data...(Werkmeister et al., 2015). Therefore and for the validation of cloud products from satellites, ground-based observing systems such as all-sky cameras are necessary."

The two sentences have been changed as suggested (p. 2, l. 21ff.):

However, the temporal resolution of satellite products is limited. From the Meteosat Second Generation (MSG) geostationary satellites, for instance, data about clouds are taken with a time resolution of 15 minutes (Werkmeister, 2015). Therefore and for the validation of cloud products from satellites, ground-based observing systems such as all-sky cameras are necessary.

- (6) p.2, line 31: replace "their" by "sensitivity".

Done

- (7) p.3, line 10: write f in italic (*f*/8)

Done

- (8) p.3, line 16: traceable to the respective standard groups of the World Radiation Center (WRC)

Done

- (9) p.4, line 2: Equation (1): Maybe add "...=  $DSR_{obs} - DSR_{cal,cf} + DL_{obs} - DL_{cal,cf}$ " to the equation, "where  $DSR_{obs}$  and  $DL_{obs}$  and  $DSR_{cal,cf}$  and  $DL_{cal,cf}$  are the observed and calculated downwelling shortwave and longwave fluxes for the all-sky and the corresponding cloud-free scenes, respectively." Then you can delete "which are both calculated separately".

Do you assume for the cloud-free calculations the same atmospheric conditions (e.g., temperature, IWV content) as they were observed during the corresponding (all-sky) measurements? It is nowhere clearly stated. You may state this also here.

As suggested, we added to Eq. 1 the following part:

$$\text{TCE} = \text{SCE} + \text{LCE} = \text{DSR}_{\text{obs}} - \text{DSR}_{\text{cfm}} + \text{DLR}_{\text{obs}} - \text{DLR}_{\text{cfm}}$$

Yes, we assume the same atmospheric conditions (temperature, IWV, etc.) under cloud-free conditions as under cloudy conditions. Therefore we added the following sentence (p. 4, l. 8ff.):

The atmospheric conditions (namely temperature and IWV) in the models are assumed to be the same under cloudy and cloud-free condition.

- (10) **p.4, line 7: I would delete "usually" (or replace by "always"). Clouds increase always the observed LW radiation, don't they?**

We changed the sentence to (p. 4, l. 13-14):

Clouds increase the measured LW radiation at the surface as they emit LW radiation.

- (11) **p.4, line 19: LibRadtran**

Done

- (12) **p.4, line 31: Include a sentence how you remove the distortion in the Image**

The following sentence has been added on p. 5, l. 8-9:

The distortion of the images is removed with a polynomial function.

- (13) **p.6, line 13: could you state a possible explanation for the opposing cloudfree/overcast conditions in winter and summer at Payerne and Davos? Similarly, after line 23, insert a new paragraph and describe the differences in cloud type between the two stations, e.g., fewer Cu and St-As at Payerne with respect to Davos but much more Cb-Ns, most likely due to deficiencies in the cloud type algorithm.**

We added a paragraph to further discuss the differences in cloud coverage between the two stations (p. 6, l. 26ff.):

The difference in cloud-free and overcast situations can be explained by the location and the topography of the two stations. In the Midlands, where Payerne is located, in autumn and winter months a common meteorological condition is an inversion, which leads to fog and thus to an overcast sky. Whereas in Davos, located in the Alps, the weather is rather dominated by thermal lift, which occurs more often in summer than in winter.

Another paragraph was added on p. 7, l. 6ff. to further discuss the distribution of cloud types:

In Davos, as determined by our algorithm, from October to May St-As is present in at least 40 % of the cases per month. This fraction of St-As is rather too high and might be due to a limitation of the cloud type algorithm. The limitation is, that the algorithm applied for Davos is trained with images from Payerne. Therefore it might be more difficult to distinguish between low-level cloud classes (e.g. St-As and Sc) in Davos. This limitation might also be responsible for the rather infrequent determination of Cu in Davos.

(14) **p.7, Fig.2 in the legend: Cb instead of Cn**

Done

(15) **p.7, line 1. "visual observations": Do you refer to routinely conducted synoptic cloud observations by trained personal, i.e. human observer?**

With visual observations we meant the visual analysis of images and therefore changed the sentence on p. 7, l. 11ff.:

This absence of the cloud class Ci-Cs in the late summer months does not match with the visual analysis of images and might be explained by the fact that the cloud detection algorithm is not sensitive enough for thin high-level clouds.

(16) **p.7, line 14: to some extent also for St-As.**

Yes the non-linearity is also seen for St-As. Therefore we added St-As as well at p. 8, l. 10-11:

This non-linear increase is clearly observed for the cumulus type clouds Cu, Sc and Cc-Ac, as well as for St-As.

(17) **p.7, lines 15-20: I would state the statistics for Ci-Cs and 8 oktas coverage for Davos, even if it is too high. Concerning the causes for this particular case, I do not believe that the erroneous values are due to the fact that the camera is not sensitive to high-level clouds. It is not reasonable that the camera detects high-level clouds with lower cloud coverage (these values seem to be reasonable) but does not for overcast conditions. Thus, I would rephrase lines 15-20 which are anyways partly difficult to understand, e.g. something like: "The median for overcast (8 oktas cloud coverage) Ci-Cs conditions in Davos is clearly too high at XX Wm-2. Manually checked images indicate a misclassification of numerous cases as Ci-Cs instead of a cloud type with a lower cloud base and/or optically thicker clouds. Alternatively, the classification as Ci-Cs could be correct, but various cloud types occur at the same time including clouds with a lower cloud base/optically thicker clouds resulting in higher LCE values for Ci-Cs. A possible reason for the misclassification could be that the algorithm is trained with a data set from Payerne." Finally, I would delete lines 20-24.**

Thanks to your comment we changed this paragraph on p. 10, l. 3ff.:

The median LCE value for Ci-Cs in Davos and eight oktas cloud coverage at  $53 \text{ Wm}^{-2}$  is clearly too high. Manually checked images indicate a misclassification of numerous cases as Ci-Cs instead of a cloud type with a lower cloud base. A possible reason for the misclassification could be that the algorithm is trained with a data set from Payerne. In general, the greater the fractional cloud coverage, the more difficult it becomes to distinguish among cloud types.

- (18) p.7, line 26: It is Table 1 (instead of 2). It would be also helpful to include the absolute or relative numbers of occurrences for the individual cloud classes and cloud coverages (in the same table or in a separate table). Indeed, some results which are not reasonable as discussed before could be also due to a limited number of occurrences for a particular cloud class and cloud cover.

We added the two tables A1 and A2 in the appendix with the absolute numbers of occurrences per cloud class and cloud fraction. Also in the text it has been further discussed, that some differences might be explained by the limited number of cases.

- (19) p. 9, line 10: "at  $36 \text{ Wm}^{-2}$ " instead of "with  $36 \text{ Wm}^{-2}$ "

Done

- (20) p. 9, line 13: I would rephrase this sentence, e.g., "The difference of the median LCE values increases with decreasing cloud coverage." or similar.

Done

- (21) p. 9, line 14/15: I would simply write "The difference might be partly due to a higher underestimation of the calculated LW cloud-free irradiances at Payerne." or similar.

The sentence has been changed as suggested.

- (22) p. 9, line 16: "higher" instead of "larger".

Done

- (23) p. 10, line 4: No new paragraph. Continue directly with "Table 2 summarizes..." on line 4 (and it is Table 2 not Table 3).

Done

- (24) p. 10, line 7: Delete "SCERel value".

Done

- (25) p. 11, line 4: "higher" instead of "lower".

Done

(26) p. 11, line 12: 2x "conditions" instead of "condition".

Done

(27) p. 11, line 13: delete "part of the shortwave radiation".

Done

(28) p. 11, line "at" instead of "with" and "range" instead of "region".

Done

(29) p. 11, lines 4-6: I would rephrase these two sentences, e.g.: "The largest contribution stems from the cloud class Cc-ac at 32 % of the cases, followed by Cu at 27 %, Sc (20 %), St-As (11 %)....."

Done

(30) p.11, line 7: "negligibly small at 0.2 %".

Done

(31) p.12, line 14: "... in 8 % of the 126,148 cloud cases, a cloud enhancement of more than 5 % SCErel is observed."

Done

(32) p.12, line 25: "Schade et al. (2007) showed..."

Done

(33) p.12, line 10: "...Davos and Payerne are summarized in Table 3 separately." (it is Table 3).

Done

(34) p.12, line 12: "...the less negative/the more positive the TCE...".

We changed the sentence on p. 15, l. 1-2:

The smaller the cloud coverage is, the less negative the TCE values are.

(35) p. 12, line 16/p. 13, line 2: "Among other reasons": You may list two or three of them. In addition to the cloud enhancement, the positive values are most likely also due to the relatively large uncertainties in the cloud-free model. In my opinion, this should be stated here.

We added two more sentences on p. 15, l. 2ff.:

Among other reasons, one reason for these positive values with smaller cloud coverages might be the cloud enhancement events as described in section 3.2.2. Another reason might be the uncertainty in the cloud type detection algorithm as well as a larger uncertainty in SCE values the larger the SZA is.

(36) p. 17, line 11: "increased" instead of "decreased".

Done

(37) p. 17/18 lines 18-21: I would rephrase this last paragraph (note: the radiation (not energy) budget would be complete if upwelling fluxes were considered) , something like: "The calculations and observations in this study are limited to daylight hours since the hemispherical sky camera operates in the visible wavelength range. However, for climate-monitoring applications cloud observations during day and night are necessary. Therefore, a new observing system (infrared cloud camera) has been developed..."

We shortened and rewrote the whole conclusions. Therefore also this last sentence has been changed.



# ~~Long-term study of cloud~~ Cloud radiative effect, cloud fraction and cloud type at two stations in Switzerland using hemispherical sky cameras

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**Abstract.** The current study analyses ~~time-series-of-the~~ cloud radiative effect during daytime depending on cloud fraction and cloud type at two stations in Switzerland over a time period of three to five years. Information about fractional cloud coverage and cloud type is retrieved from images taken by visible all-sky cameras. Cloud base height (CBH) data are retrieved from a ceilometer and integrated water vapour (IWV) data from GPS measurements. The longwave cloud radiative effect (LCE) for low-level clouds and a cloud coverage of 8 ~~oktas-oktas~~ has a median value between 57 and 71 59 and 72  $\text{Wm}^{-2}$ . For mid- and high-level clouds the LCE is significantly lower. It is shown that the fractional cloud coverage, the ~~cloud-base-height (CBH) and integrated water vapour (IWV)~~ CBH and IWV all have an influence on the magnitude of the LCE. These observed dependences have also been modelled with the radiative transfer model MODTRAN5. The relative values of the shortwave cloud radiative effect ( $\text{SCE}_{\text{rel}}$ ) for low-level clouds and a cloud coverage of 8 ~~oktas are between -88 to -61~~ oktas are between -90 to -62 %. Also here the higher the cloud is, the less negative the  $\text{SCE}_{\text{rel}}$  values are. In cases where the measured direct radiation value is below the threshold of  $120 \text{ Wm}^{-2}$  (occulted sun) the  $\text{SCE}_{\text{rel}}$  decreases substantially, while cases where the measured direct radiation value is larger than  $120 \text{ Wm}^{-2}$  (visible sun) lead to a  $\text{SCE}_{\text{rel}}$  of around 0 %. In ~~13~~ 14 % and ~~8~~ 10 % of the cases in Davos and Payerne respectively a cloud enhancement has been observed with a maximum in the cloud class cirrocumulus-altocumulus at both stations. The calculated median total cloud radiative effect (TCE) values are negative for almost all cloud classes and cloud coverages.

## 1 Introduction

The influence of clouds on the radiation budget and radiative transfer of energy in the atmosphere persist the greatest sources of uncertainty in the simulation of climate change (Boucher *et al.*, 2013). Small changes in cloudiness and radiation can have large impacts on the Earth's climate. There are two competing influences of clouds on the surface radiation budget (Sohn and Bennartz, 2008): On one hand, clouds reflect incoming shortwave radiation and thus diminish the incoming energy on the Earth's surface. On the other hand, they prevent longwave radiation from the surface and lower atmosphere from escaping the atmosphere. Radiation is the energy source which modifies the atmospheric thermodynamic structure, the Earth's

general circulation and the climate system (Sohn and Bennartz, 2008). The effect of clouds is not only of importance in the ~~long term~~ long-term temporal and spatial averages but also on shorter timescales (seconds to minutes). Furthermore, the exchange of energy due to the formation of clouds and precipitation is an important component of the global water cycle and in turn of climate change (Trenberth, 2011). Thus the influence of clouds has to be measured and analysed in more detail.

5 Not only the cloud amount but also other cloud parameters such as e.g. cloud type and cloud optical thickness are of importance. The physical parameters defining the various cloud types may have distinct effects on radiation of different wavelengths. For example optically thin and high-level clouds have a relatively small effect on the downward shortwave radiation, whereas low-level and thick clouds scatter and absorb a large part of the solar radiation and re-emit it as thermal radiation in all directions. Thus cloud type variations can alter both shortwave and longwave radiation fluxes due to changes in cloud levels, water  
10 content and cloud temperatures (Chen et al., 2000; Allan, 2011). However, not only different cloud types, but also clouds of the same type may have a distinct influence on the surface radiation budget due to their macrophysical (cloud coverage and geometry) and microphysical properties (e.g. optical thickness and particle size distribution) (Pfister et al., 2003). The distribution, frequency and length of occurrence of different cloud types, and the cloud amount in general, may cause a change in climate variations and climate feedback (Bony et al., 2006; Norris et al., 2016). In order to assess the cloud climate feedback,  
15 also cloud independent parameters such as time of year or time of day are of importance (Allan, 2011). Knowledge about the cloud type also allows conclusions to be drawn regarding the current atmospheric motions (Chen et al., 2000). Thus additional information about the cloud type is crucial to categorize the cloud radiative effect (Futyan et al., 2005).

In detailed numerical weather and climate prediction models, cloud properties (cloud base height, cloud cover and cloud thickness) and the physical processes responsible for the formation and dissipation of clouds are often approximations and parametrizations (e.g. ~~Bony et al. (2006); Allan et al. (2007); Zelinka et al. (2014); Sherwood et al. (2015)~~) (e.g. Bony et al., 2006; Allan et al., 2006).  
20 In order to contribute to the accuracy of the representation of clouds in atmospheric prediction models, there is need for satellite and ground-based in situ measurements (Sohn, 1999; Jensen et al., 2008; Su et al., 2010; Roesch et al., 2011). Satellite measurements have the advantage of covering a ~~broader wider~~ broader wider area. Mainly over the oceans it is almost the only data source to obtain information about cloud coverage and cloud type (Ohring et al., 2005). However, the temporal resolution of satellite products is limited. From the Meteosat Second Generation (MSG) geostationary satellites, for instance, data about clouds are  
25 taken with a time resolution of 15 minutes (Werkmeister et al., 2015). ~~A better temporal resolution may be obtained by the measurement of clouds with e.g. Therefore and for the validation of cloud products from satellites~~, ground-based observing systems such as all-sky cameras are necessary.

For several years, all-sky cloud cameras have been in use world-wide in order to collect continuous information about clouds  
30 from the surface. Many studies already determined cloud coverage based on all-sky camera images (e.g. ~~Long et al. (2006); Kazantzidis et al. (2012); Alonso et al. (2014)~~) (e.g. Long et al., 2006; Kazantzidis et al., 2012; Alonso et al., 2014). Heinle et al. (2010) presented a method for using all-sky camera images to classify cloud types. Wacker et al. (2015) applied, with slight modifications, this algorithm to determine six cloud classes automatically with a mean success rate of 50 to 70 %. The current study uses the cloud type detection and the cloud fraction algorithm presented in Wacker et al. (2015).

35 The current study presents ~~time-series a study~~ time-series a study of cloud radiative ~~effects-effect~~ effects-effect at the surface depending on cloud fraction and

cloud types at two stations in Switzerland over a time period of 3-5 years. The data and methods (including the description of the algorithms and the models) are described in section 2. The ~~time-series-of-the~~ cloud radiative effect in the longwave and shortwave ~~regions-ranges~~ at the two stations Davos and Payerne and ~~their-sensitivity~~ analyses are presented and discussed in section 3. Conclusions are outlined in section 4.

5

## 2 Data and Methods

### 2.1 Data

Data are available from two stations in Switzerland. The stations are located at two altitude levels, Payerne, located in the Midlands (46.49°N, 6.56°E, 490 m asl) and Davos, located in the Swiss Alps (46.81°N, 9.84°E, ~~1594~~1,594 m asl). At both  
10 of these stations a visible all-sky camera has been installed. The camera type in Payerne is a VIS-J1006, manufactured by Schreder GmbH (www.schreder-cms.com). This camera system consists of a commercial digital camera (Canon Power Shot A60) with a fisheye lens and a glass dome on top to protect the camera from rain and dust. This camera is sensitive in the red-green-blue (RGB) region of the spectrum and takes two images every five minutes with a resolution of 1200 × 1600 pixels each. The two images taken, one just after the other one, have different exposure times (1/500 s and 1/1600 s, respectively) but  
15 the same fixed aperture of ~~f~~f/8.

The camera system in Davos is a Q24M from Mobotix (www.mobotix.com). It is a commercial surveillance camera with a fisheye lens sensitive in the RGB as well. The resolution of the images is the same as that for the camera in Payerne. In Davos, one image is taken every minute with an exposure time of 1/500 s. The Mobotix camera is ventilated and installed on a solar tracker with a shading disk.

20 The radiation data are retrieved from Kipp and Zonen CMP22 pyranometers (shortwave; 0.3 - 3  $\mu\text{m}$ ) and from Kipp and Zonen CG4 pyrgeometers (longwave; 3 - 100  $\mu\text{m}$ ) at both stations. All the instruments are daily cleaned and traceable to the respective standard groups of the World Radiation Center (WRC). The temperature data used in the current study are measured at 2 m height at both stations. The integrated water vapour (IWV) data are based on GPS measurements (*Bevis et al.*, 1992; *Hagemann et al.*, 2003) and retrieved from the STARTWAVE (STudies in Atmospheric Radiative Transfer and Water Vapour  
25 Effects) database (*Morland et al.*, 2006). Aerosol optical depth ~~data~~(AOD) data, used for the shortwave cloud-free model, are retrieved from precision filter radiometers (PFR, manufactured by PMOD/WRC). Ceilometer data for the retrieval of the cloud base height (CBH) are only available in Payerne. At this station a CHM15k ceilometer from Jenoptik (now Lufft Mess- und Regeltechnik GmbH) is installed (*Wiegner and Geiß*, 2012).

For the Davos station ~~a time-series-of~~ the cloud radiative effect (CRE) has been calculated from August 7, 2013 to April 30,  
30 2017 with a time resolution of one minute. Data have only been taken into account for daytime measurements when the sun is located minimum five degrees above the horizon and the mountains. For Payerne, the ~~time-series-of-the~~ study of CRE includes data from January 1, 2013 to April 30, 2017 with a time resolution of five minutes. Data ~~have only been taken into account for daytime measurements when the full sun disk is located above the horizon and the mountains. Cloud radiative effect considered~~

are during daytime with a solar zenith angle (SZA) of maximum 78°. Cloud camera data availability in these periods is around 98 % and 86 % for Davos and Payerne respectively which mainly results from occasional data gaps of 1 to 3 consecutive days. The lower data availability in Payerne can be explained by two longer time periods of more than 20 consecutive days (one in winter and one in summer) when no camera data are available.

5

## 2.2 Cloud Radiative Effect

In the current study, the cloud radiative effect (CRE) is defined as a radiation measurement value minus a modelled clear-sky cloud-free value. The total cloud radiative effect (TCE) is divided into shortwave cloud radiative effect (SCE) and longwave cloud radiative effect (LCE)

$$10 \quad TCE = SCE + LCE = \underline{DSR_{obs} - DSR_{cfm} + DLR_{obs} - DLR_{cfm}} \quad (1)$$

which are both calculated separately by comparing an observed downward radiation measurement (shortwave (SW):  $DSR_{obs}$ , longwave (LW):  $DLR_{obs}$ ) with a modelled downward radiation value (SW:  $DSR_{cfm}$  and LW:  $DLR_{cfm}$ ). For our calculations, only measurements from downward radiation during daytime are taken into account. The atmospheric conditions (namely temperature and IWV) in the models are assumed to be the same under cloudy and cloud-free conditions. In the following, the

15 SCE values are given as relative values ( $SCE_{rel}$ ) and calculated using Eq. 2.

$$SCE_{rel} = SCE / \underline{SCE_{CSM} DSR_{cfm}} * 100\% \quad (2)$$

where  $SCE_{CSM} DSR_{cfm}$  is the modelled clear-sky cloud-free irradiance value for the corresponding date and time.  $SCE_{rel}$  is used due to the fact that different solar zenith angles lead to large differences in the absolute SCE values. Clouds usually increase the measured LW radiation at the surface as they emit LW radiation. Shortwave radiation measured at the surface is

20 usually reduced by clouds as they reflect SW radiation back to space.

## 2.3 Clear-Sky-Cloud-free Models

For the calculation of the cloud radiative effects two clear-sky cloud-free models, one for the shortwave and the other one for the longwave regionrange, are needed. The clear-sky cloud-free model for the longwave is an empirical model with input of measured surface temperature and integrated water vapour (IWV) values and a climatology of the atmospheric temperature profile (Wacker *et al.*, 2014). Comparing the LW radiation measurements of the clear-sky cloud-free cases, detected in the aforementioned time period, with the LW radiation values of the clear-sky cloud-free model gives a mean difference of  $-0.8 \pm 3.9 - 0.9 \pm 3.9$  Wm<sup>-2</sup> and  $-2.8 \pm 6.6 - 0.5 \pm 8.1$  Wm<sup>-2</sup> for Davos and Payerne respectively. Thus this difference lies within measurement uncertainty as it has also been shown by Wacker *et al.* (2014).

30 The shortwave clear-sky cloud-free model (used in Eq. 2) is a lookup table (LUT) based on radiative transfer model calculations using LibRadtran-LibRadtran (Mayer and Kylling, 2005). The input of the model is a standard atmosphere includ-

ing several measured atmospheric parameters: solar zenith angle (SZA), aerosol conditions (~~angstrom~~-Angstrom coefficient and aerosol optical depth (AOD), both interpolated over one day) and IWV. The air mass is calculated with the formula presented by *Kasten and Young* (1989). The ~~lookup-table~~-LUT is different for the two stations Davos and Payerne, considering a different range of values that might occur. Measured values of IWV, SZA and aerosol content are then interpolated

5 with the ~~lookup-table~~-LUT and downward shortwave ~~clear-sky-cloud-free~~ irradiance values are available for all the single time steps and the corresponding atmospheric conditions. The difference between SW measurement and the ~~clear-sky model is~~  $4.7 \pm 19.6$  cloud-free model depends on the SZA. The bigger the SZA, the higher the mean difference. In Davos, the mean difference changes from  $7.2 \pm 20.7$   $\text{Wm}^{-2}$  ( $0.5 \pm 6.2$  to  $0.9 \pm 2.6$  %) and  $-0.5 \pm 45.8$  for data with  $\text{SZA} < 50^\circ$  to  $5.7 \pm 14.7$   $\text{Wm}^{-2}$  ( $-0.4 \pm 9.9$  %) for Davos and Payerne respectively.  $1.1 \pm 3.8$  %) for data with  $\text{SZA} > 50^\circ$ . In Payerne, the

10 mean difference is  $7.3 \pm 41.7$   $\text{Wm}^{-2}$  ( $1.0 \pm 5.2$  %) for data with  $\text{SZA} < 50^\circ$ . The mean difference is with  $3.3 \pm 34.1$   $\text{Wm}^{-2}$  ( $0.6 \pm 8.9$  %) slightly larger for data with SZA from  $50$  to  $78^\circ$ .

## 2.4 Cloud Fraction and Cloud Type Retrievals

The calculation of the fractional cloud coverage is based on the all-sky cloud camera images from the aforementioned systems. Before calculating the cloud amount the images must be preprocessed. The distortion of the images ~~has to be removed~~ is removed with a polynomial function. Additionally a horizon mask must be defined since Davos is located between two mountain ridges. For both stations the horizon mask has been defined on the basis of an individual ~~clear-sky-cloud-free~~ image. After the preprocessing of the images a colour ratio (the sum of the blue to green ratio plus the blue to red ratio) is calculated per pixel (*Wacker et al.*, 2015). This calculated colour ratio is compared with a reference ratio value which is defined empirically

20 in order to do the cloud classification per pixel. The reference value for Davos is 2.2 and the one for Payerne 2.5. These values are different due to the differences in camera systems and settings. After comparing the calculated ratio with the reference value a decision can be made per pixel on a classification of cloud or ~~clear-sky-cloud-free~~. The fractional cloud coverage is then calculated as the sum of all cloudy pixels divided by the total number of sky pixels. For historical reasons the fractional cloud coverage is given in ~~oetas-oktas~~ (*CIMO*, 2014). The classification of ~~oetas-oktas~~ is taken from *Wacker et al.* (2015). Thus zero

25 ~~oeta-okta~~ cloud coverage or cloud-free is defined as 0 - 5 % fractional cloud coverage. Thus cloud-free does not necessarily mean no clouds at all. On the other end of the scale, eight ~~oetas-oktas~~ is defined as a fractional cloud coverage of 95 % and more, which implies that it is not necessarily a fully covered sky. ~~Oeta-Okta~~ 1 - 7 are defined in between with steps of 12.75 % fractional cloud coverage. For 65 - 85 % of the cases (in comparison to different cloud fraction retrieval instruments), the success rate of the fractional cloud cover calculation is  $\pm 1$  ~~oeta-okta~~ (*Wacker et al.*, 2015).

30 The algorithm of *Heinle et al.* (2010) allows the classification of clouds based on statistical features retrieved from the all-sky cloud images. This algorithm has been slightly adapted by *Wacker et al.* (2015) and is the one used for the current analysis. The classification is done by first calculating ~~thirteen-twelve~~ spectral, textural and radiative features. The features under consideration are the mean of the red and the mean of the blue channel, standard deviation and the skewness both of the blue channel, and the differences between the red and green, red and blue, and green and blue channels. The textural features are the energy,

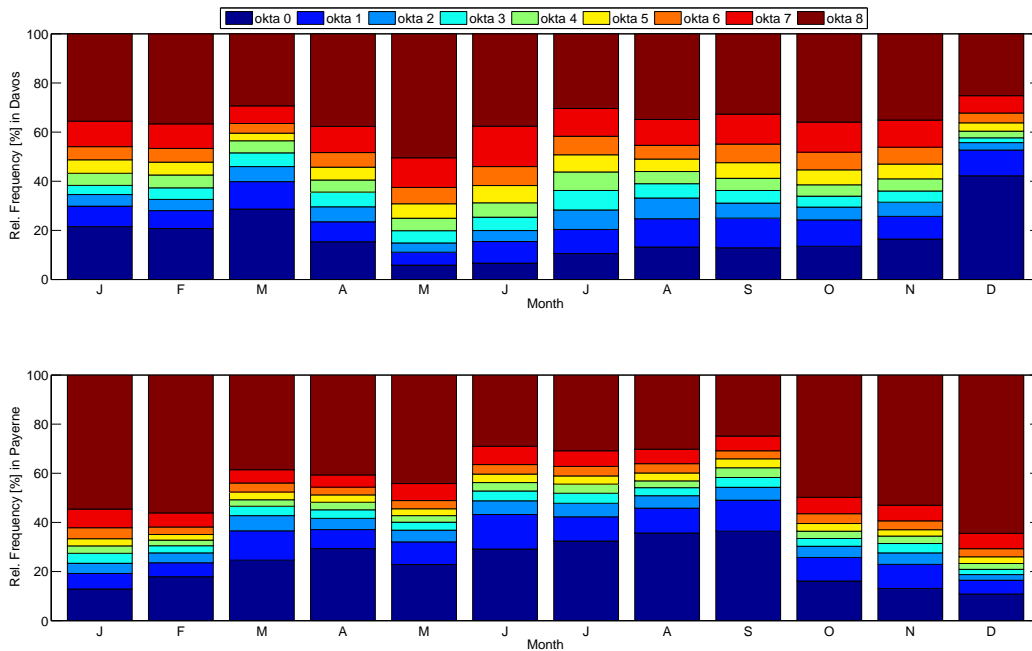
contrast and homogeneity of the blue channel and the total cloud coverage. The radiative feature longwave cloud radiative effect has been added by *Wacker et al. (2015)* after testing its (positive) influence on the mean success rate of the cloud type recognition. The classifier used is the k-nearest-neighbour (knn) method, which is a supervised method. The training set to apply the knn method has been determined with visual analysis of the images. The training set is only available for the Payerne station. Thus, for both stations, Davos and Payerne, the same training set has been used. The training set contains only images with one cloud type present. However, the training images display a wide variety in the shape and position of the ~~clouds~~clouds, but not necessary in cloud fractions. In the classification procedure different cloud types per image might be detected, however as a result, only the one with the most hits is chosen. Thus only one cloud type per image is determined, although several might be present. The seven classes studied are cloud-free (Cf), cirrus-cirrostratus (Ci-Cs), cirrocumulus-altocumulus (Cc-Ac), stratocumulus (Sc), stratus-altostratus (St-As), cumulus (Cu) and cumulonimbus-nimbostratus (Cb-Ns). In the following, low-level clouds consist Cu, Sc, St-As and Cb-Ns. The cloud class Cc-Ac is a mid-level cloud class and Ci-Cs is a high-level cloud class. According to *Wacker et al. (2015)*, for a random data set of Davos, the situation Cf was correctly classified in more than 85 % of cases followed by Ci-Cs (65 %) and Cu (more than 50 % of the cases). For Payerne, around 80 % of the manually classified Sc clouds are also classified as such with the automatic algorithm and a random data set. The second most correctly detected cloud class is Cf (more than 70 % of the cases) and Cb-Ns (68 % of the cases). In the average, the success rates are 57 % and 55 % for Davos and Payerne respectively (*Wacker et al., 2015*).

### 3 Results and Discussion

#### 3.1 ~~Time Series Occurrence~~ of Cloud ~~Radiative Effect~~Fraction and Cloud Types

The data sets for the calculation of the cloud radiative effect (CRE) consist of ~~694,000 and 162,398~~ 595,806 and 117,763 images for Davos and Payerne respectively. In Davos, the cloud coverage is eight ~~oetas for 34~~oktas for 35 % of the data set. In 17 % of the cases the cloud coverage is zero ~~oeta~~okta, which means a fractional cloud coverage of maximum 5 %. Seven ~~oetas~~oktas cloud coverage occurs in 11 % of the cases followed by one ~~oeta~~okta (10 %). Two to six ~~oetas~~oktas cloud coverage are all equally distributed in 5 to 6 % of the cases.

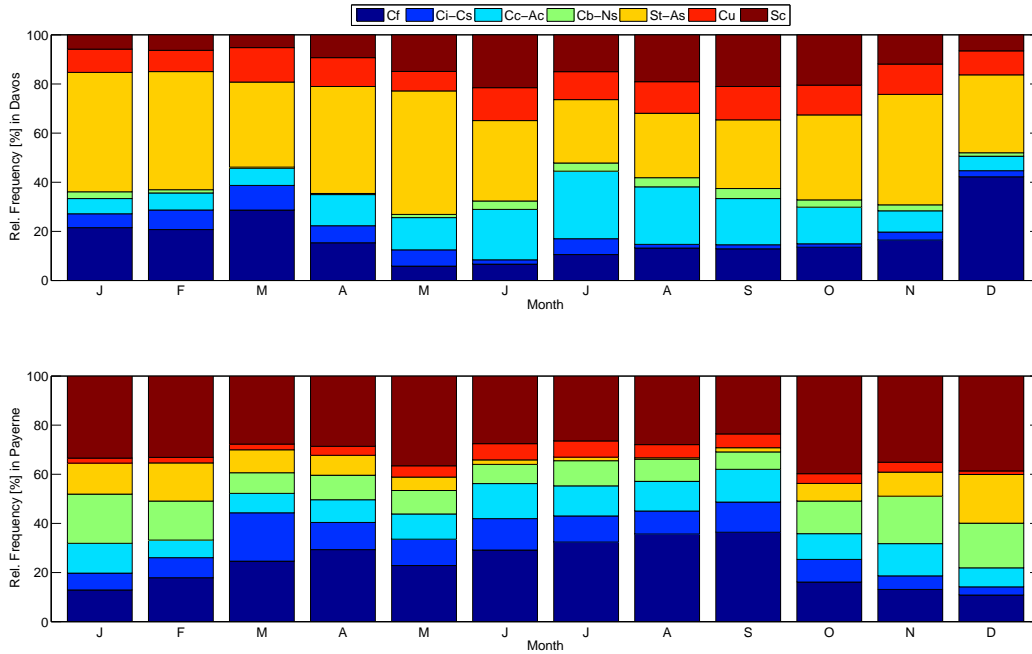
Also in Payerne, a cloud coverage of eight ~~oetas~~oktas is determined in most of the cases (41 %), followed by zero ~~oeta in~~22okta in 25 % of the cases. In 10 % of the cases a cloud coverage of 1 ~~oeta~~okta is determined followed by seven ~~oetas~~(7oktas (6 % of the cases) and two ~~oetas~~oktas (5 %). A cloud coverage of three to six ~~oetas~~oktas is determined in 3 - 4 % of the cases. The distribution of the cloud coverage over the months is shown for Davos and Payerne separately in Figure 1. The colours indicate ~~oeta~~okta cloud coverages. In the winter half year (with a maximum in March and December) the sky is more often cloud-free than in the summer half year in Davos. In contrast, in May the sky is covered with eight ~~oetas~~oktas in almost half of the cases. Cloud coverages of 1 to 7 ~~oetas~~oktas are quite equally distributed over the months. In Payerne the situation is opposite for cloud-free days with more frequent eight ~~oetas~~oktas cloud coverage in wintertime whereas cloud-free situations are more common during summertime. Also in Payerne, cloud coverages of 1 to 7 ~~oetas~~oktas are fairly equally distributed.



**Figure 1.** Relative frequencies of cloud coverages in 1 to 8 ~~okta~~-okta divisions (all cloud types together) for the two stations Davos (left) and Payerne (right).

The difference in cloud-free and overcast situations can be explained by the location and the topography of the two stations. In the Midlands, where Payerne is located, in autumn and winter months a common meteorological condition is an inversion, which leads to fog and thus to an overcast sky. Whereas in Davos, located in the Alps, the weather is rather dominated by thermal lift, which occurs more often in summer than in winter.

- 5 Regarding the distribution of the cloud coverages in ~~oktas~~-oktas throughout the day, no real pattern can be observed in Davos. In Payerne there are more cloud-free conditions in the early morning than later in the day. The other ~~okta~~-okta cloud coverages are also equally distributed throughout the day.
- In Davos, of the ~~694,000-595,806~~ cases, St-As, with ~~3637~~ % of the cloud cases, is the cloud type that is most detected in the studied time period. The second and third most detected sky conditions in Davos are Cf and Cc-Ac with 17 % and 14 %
- 10 respectively, followed by Sc (13 %), Cu (12 %), Ci-Cs (5 %) and Cb-Ns (~~32~~ %).
- In Payerne, of the ~~162,398-117,763~~ sky images, in ~~2831~~ % of the cases the cloud type Sc is detected. This is followed by Cf in around ~~2225~~ % of cases, Cb-Ns(~~17~~%), Cc-Ac (~~13~~%), and Ci-Cs (~~9~~each ~~11~~ %), St-As (~~67~~ %) and Cu (4 %).
- Figure 2 shows the relative frequencies of the cloud classes per month for the two stations Davos and Payerne separately and all cloud coverages together. In Davos, as determined by our algorithm, from October to May St-As is present in at least 40 %
- 15 of the cases per month. ~~The cloud~~-This fraction of St-As is rather too high and might be due to a limitation of the cloud type



**Figure 2.** Relative frequencies of all cloud classes per month (all cloud coverages together) for the two stations Davos (left) and Payerne (right). Sc: stratocumulus, Cu: cumulus, St-As: stratus-altostratus, Cb-Ns: cumulonimbus-nimbostratus, Cc-Ac: cirrocumulus-alto cumulus, Ci-Cs: cirrus-cirrostratus, Cf: cloud-free.

algorithm. The limitation is, that the algorithm applied for Davos is trained with images from Payerne. Therefore it might be more difficult to distinguish between low-level cloud classes (e.g. St-As and Sc) in Davos. This limitation might also be responsible for the rather infrequent determination of Cu in Davos. The cloud class Cc-Ac is more often present in summertime than in wintertime. Ci-Cs is almost absent in the months August to October. This absence of the cloud class Ci-Cs in the late summer months does not match with the visual [observation-analysis of images](#) and might be explained by the fact that the [camera-system-cloud detection algorithm](#) is not sensitive [for-the-enough-to-detect](#) thin high-level clouds. The largest fraction of cloud type in Payerne is Sc for all months. The cloud classes Cb-Ns and St-As are both more often observed during wintertime than during summertime. The larger frequency of these two cloud types agree with the fact that there is more [often](#) fully covered sky in wintertime than summertime.

10 Regarding the distribution of the cloud classes throughout the day, there are no large differences in the occurrence of cloud types per time of day. The distribution is quite flat for both stations.



## 3.2 Cloud Radiative Effect

### 3.2.1 Longwave Cloud Effect

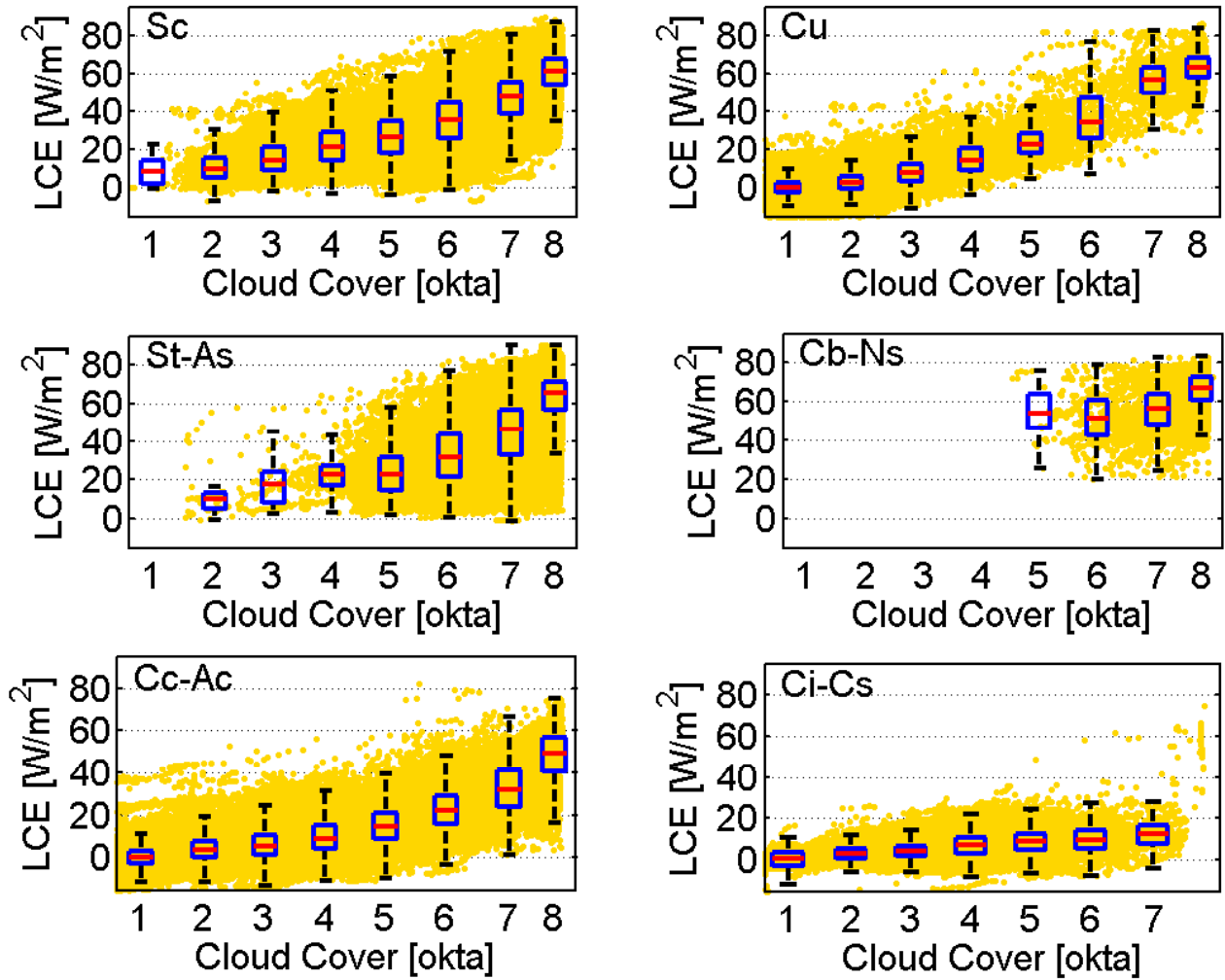
As mentioned in section 2.2 Applying Equation 1, the longwave cloud radiative effect (LCE) is calculated for Davos and Payerne and the six cloud classes separately. The dependence of LCE on fractional cloud cover for the above mentioned time period for all six cloud classes is shown for Davos in Figure 3. The boxplots in the figure show the median (red line), the interquartile range (blue box) and the values that are within 1.5 times the interquartile range of the box edges (black line) per oeta-okta cloud coverage.

Figure 3 shows a non-linear increase in the LCE with increasing fractional cloud coverage for some cloud classes. This non-linear increase is clearly observed for the cumulus type clouds Cu, Sc and Cc-Ac. ~~At present, it is not possible to explain this, as well as for St-As. Clouds at different zenith angles in the sky have a stronger or weaker impact on the downward longwave radiation measured at the surface. In case the zenith angles of the clouds are not equally distributed in our analysed time period, this might be a reason for this non-linearity in LCE. However, we have not analysed it in more detail yet and is subject of a future study.~~ The cloud classes St-As and Cb-Ns are mainly present with a cloud coverage of 5 oetas-oktas and more. The ~~LCE values median LCE value~~ for Ci-Cs in Davos and eight ~~oetas cloud coverage are~~ oktas cloud coverage at  $53 \text{ Wm}^{-2}$  is clearly too high. ~~Therefore no statistical values were calculated for this data set. Several reasons might be responsible for these too high values. One reason is that the camera is not sensitive enough to detect thin~~ Manually checked images indicate a misclassification of numerous cases as Ci-Cs clouds. Another reason might instead of a cloud type with a lower cloud base. A possible reason for the misclassification could be that the ~~cloud type~~ algorithm is trained with a data set from Payerne, which may result in a misclassification of the thin and high-level clouds. That some data points are in the group of Ci-Cs and eight ~~oetas cloud coverage is the result of a misclassification of the cloud type with the algorithm. These manually checked misclassified data points result in the detection of a weakness of the algorithm. The~~ In general, the greater the fractional cloud coverage, the more difficult it becomes to distinguish among cloud types. ~~This weakness can be explained by the fact that the greater the cloud coverage, the more difficult it becomes to distinguish textural features with the knn method and thus to distinguish among cloud types.~~ For the cloud type Cc-Ac there are several LCE values of around  $40 \text{ Wm}^{-2}$  and small cloud coverages. These high values are obtained in early mornings when the cloud is located in the vicinity of the horizon.

Table 1 gives an overview of the median values and their interquartile range of the LCE per oeta-okta cloud coverage for the six cloud classes for Davos and Payerne separately. The number of cases per cloud class and cloud fraction can be found in the appendix (Table A1 and A2).

In Davos, the highest median LCE for a cloud coverage of 8 oetas-oktas is observed for the low-level cloud classes Cb-Ns, St-As, Cu and Sc with a maximum influence on the downward longwave radiation at the surface for Cb-Ns ( $6867 \text{ Wm}^{-2}$ ). The mid-level and thinner cloud class Cc-Ac has a lower median LCE of  $49 \text{ Wm}^{-2}$  for a cloud coverage of 8 oetasoktas. Clearly lower is the median LCE value for the high-level cloud class Ci-Cs and 7 oetas-oktas cloud coverage ( $1213 \text{ Wm}^{-2}$ ). Also for other cloud coverages median LCE values of the three low-level cloud types Sc, Cu and St-As stay in the same range.

Although the numbers differ between the two stations, the same pattern holds also for Payerne, namely that the lower the cloud,



**Figure 3.** Dependence of LCE on cloud coverage for Davos for cloud classes stratocumulus (Sc), cumulus (Cu), stratus-altostratus (St-As), cumulonimbus-nimbostratus (Cb-Ns), cirrocumulus-alto cumulus (Cc-Ac) and cirrus-cirrostratus (Ci-Cs). Data points (yellow dots) and box plots per  $\text{okta}$  with median (red line), interquartile range (blue box) and spread without outliers.

**Table 1.** Median and interquartile range of longwave cloud radiative effect values [ $\text{Wm}^{-2}$ ] per oeta-okta for the two stations Davos (DAV) and Payerne (PAY) and six cloud classes stratocumulus (Sc), cumulus (Cu), stratus-altostratus (St-As), cumulonimbus-nimbostratus (Cb-Ns), cirrocumulus-altocumulus (Cc-Ac) and cirrus-cirrostratus (Ci-Cs).

cc [ <u>oetaokta</u> ]	station	Sc [ $\text{Wm}^{-2}$ ]	Cu [ $\text{Wm}^{-2}$ ]	St-As [ $\text{Wm}^{-2}$ ]	Cb-Ns [ $\text{Wm}^{-2}$ ]	Cc-Ac [ $\text{Wm}^{-2}$ ]	Ci-Cs
1	DAV	<u>9-8 (2,16)</u> <u>14</u>	0 (-2,3)	- (-,-)	- (-,-)	0 ( <u>-2-3</u> ,3)	1 (-
	PAY	<u>1(-3,7)</u> <u>8 (2,13)</u>	<u>1(-4,6)</u> <u>4 (-2,9)</u>	<u>6(2,8)</u> <u>(-,)</u>	- (-,-)	<u>0(-4,5)</u> <u>4 (-1,9)</u>	<u>0(-4</u>
2	DAV	<u>11(6,16)</u> <u>9 (5,15)</u>	3 (0,6)	<u>8(4,13)</u> <u>10 (5,14)</u>	- (-,-)	4 (0,8)	3
	PAY	<u>5(-1,12)</u> <u>14 (8,22)</u>	<u>10(4,18)</u> <u>13 (6,21)</u>	<u>7(3,20)</u> <u>(14,30)</u>	<u>8(-1,4)</u> <u>2 (-,-)</u>	<u>5(0,13)</u> <u>13 (5,20)</u>	<u>4(0,</u>
3	DAV	15 ( <u>10,22</u> <u>9,21</u> )	8 ( <u>4</u> ,13)	<u>17(7,23)</u> <u>18 (8,24)</u>	- (-,-)	<u>6-5</u> (1,11)	4
	PAY	<u>4(-1,14)</u> <u>39 (22,53)</u>	<u>18(11,26)</u> <u>21 (14,29)</u>	<u>27(21,35)</u> <u>30 (23,36)</u>	<u>20(4,38)</u> <u>(-,)</u>	<u>12(4,22)</u> <u>18 (10,27)</u>	<u>7(3,1</u>
4	DAV	<u>22-21</u> (15, <u>30</u> <u>29</u> )	<u>15(-10,2)</u> <u>14 (9,20)</u>	<u>24(18,30)</u> <u>23 (17,28)</u>	<u>64(52,75)</u> <u>(-,)</u>	9 ( <u>5,16</u> <u>4,15</u> )	7 (
	PAY	<u>19(7,35)</u> <u>36 (25,47)</u>	<u>22(-16,29)</u> <u>26 (19,32)</u>	<u>37(28,45)</u> <u>38 (31,46)</u>	<u>33(-11,53)</u> <u>66 (51,75)</u>	<u>18(-9,29)</u> <u>23 (15,33)</u>	<u>10(-5,</u>
5	DAV	27 ( <u>19</u> <u>18,35</u> )	<u>23(-19,29)</u> <u>22 (18,28)</u>	23 (15, <u>33</u> <u>32</u> )	<u>61(-48,7)</u> <u>54 (46,64)</u>	15 (9,21)	9
	PAY	<u>31(18,43)</u> <u>37 (27,47)</u>	<u>25(-18,32)</u> <u>29 (22,34)</u>	<u>36(29,51)</u> <u>37 (32,49)</u>	<u>39(-20,55)</u> <u>57 (50,68)</u>	<u>23(-13,33)</u> <u>27 (18,37)</u>	<u>12(-7,1</u>
6	DAV	<u>36-35</u> (26,44)	<u>35-34</u> (26, <u>49</u> <u>47</u> )	32 (22, <u>45</u> <u>44</u> )	<u>52-51</u> (42, <u>67</u> <u>60</u> )	22 (16,29)	9
	PAY	<u>37(-26,49)</u> <u>41 (31,52)</u>	<u>32(-25,40)</u> <u>36 (28,44)</u>	<u>44(30,68)</u> <u>41 (32,64)</u>	<u>45(-25,57)</u> <u>58 (50,66)</u>	<u>27(-17,38)</u> <u>32 (22,42)</u>	<u>15(-10,</u>
7	DAV	<u>47(38,55)</u> <u>48 (39,56)</u>	57 ( <u>51,64</u> <u>50,63</u> )	47 ( <u>32,57</u> <u>33,56</u> )	<u>58(-50,68)</u> <u>56 (48,64)</u>	32 (24,41)	<u>12-</u>
	PAY	<u>44(32,54)</u> <u>47 (36,56)</u>	<u>57(-37,5)</u> <u>4 (33,65)</u>	65 ( <u>54,71</u> <u>50,73</u> )	<u>51(-37,61)</u> <u>57 (49,64)</u>	<u>33(-23,40)</u> <u>36 (28,46)</u>	<u>17(-12,</u>
8	DAV	61 (54,67)	<u>64-63</u> (58, <u>69</u> <u>68</u> )	65 (56,71)	<u>68(-62)</u> <u>67 (61,73)</u>	49 (40,57)	.
	PAY	<u>57(-47,65)</u> <u>59 (49,67)</u>	<u>59(-52,65)</u> <u>62 (58,72)</u>	<u>71(-66,75)</u> <u>72 (67,76)</u>	<u>61(-52,69)</u> <u>63 (54,70)</u>	<u>36(-23,49)</u> <u>37 (26,51)</u>	<u>20(-15,</u>

the higher the LCE value. Thus for Payerne, the four low-level cloud types (Sc, Cu, St-As and Cb-Ns) and eight oetas-oktas cloud coverages have median LCE values of 57-59 - 71-72  $\text{Wm}^{-2}$  (with interquartile ranges of maximum  $\pm 9 \pm 10$   $\text{Wm}^{-2}$ ). The median LCE value for the mid-level cloud class Cc-Ac and eight oetas-oktas cloud coverage is with 36 at 37  $\text{Wm}^{-2}$  clearly lower than the values for the low-level clouds and also in comparison with the same values-value in Davos. The median LCE value for the high-level cloud class Ci-Cs and 8 oetas-is-around-20oktas is around 22  $\text{Wm}^{-2}$ . This value is only slightly lower for smaller cloud coverages.

The difference of the median LCE values of-between the two stations differ-the-more-the-smaller-the-cloud-coverage-is-increases with decreasing cloud coverage. Except Sc and Cb-Ns, the LCE values are generally larger for the station Payerne in comparison with Davos. One-part-of-the-The difference might be explained-with-the-fact-that-the-LW-clear-sky-model-for-Payerne-is underestimating-more-the-measurements-partly due to a higher underestimation of the calculated LW cloud-free irradiances at Payerne. Another explanation for this difference might be that Payerne is located at a lower altitude level and thus the cloud base temperature is larger-higher, which leads to a larger emission of LW radiation. Some of the differences might also occur due to a limited number of cases in the specific groups (see Table A1 and A2). Thus, some of the numbers have to be taken with caution.

### 15 3.2.2 Shortwave Cloud Effect

**Table 2.** Median and interquartile range of relative shortwave cloud radiative effect values [%] per  $\text{oeta-okta}$  for the two stations Davos (DAV) and Payerne (PAY) and six cloud classes stratocumulus (Sc), cumulus (Cu), stratus-altostratus (St-As), cumulonimbus-nimbostratus (Cb-Ns), cirrocumulus-altocumulus (Cc-Ac) and cirrus-cirrostratus (Ci-Cs).

cc [ $\text{oeta-okta}$ ]	station	Sc [%]	Cu [%]	St-As [%]	Cb-Ns [%]	Cc-Ac [%]	Ci-Cs [%]
1	DAV	4 (0-1,5)	1 (-2-1,4)	- (-,-)	- (-,-)	- (-,-)	1 (-1,1)
	PAY	-9 (-32,6-6 (-28,5))	1 (-31-29,9)	-70 (-70,-70 (-,-))	- (-,-)	3 (-18,-18)	
2	DAV	2 (-22,11)	2 (-83 (-5,7))	11 (-7,16-10 (6,15))	- (-,-)	3 (-17,-17)	
	PAY	-5 (-36,10-7 (-37,7))	-14 (-53-13 (-52,12))	-43 (-58,-31-37 (-42,-15))	-35 (-69,-4 (-,-))	-17 (-19,-19)	
3	DAV	-4 (-50-49,13)	3 (-31,95 (-23,10))	16 (-7,29-15 (11,27))	- (-,-)	3 (-20,-20)	
	PAY	-54 (-55 (-68,-37-39))	-27 (-28 (-56,12))	-38 (-51,-24-32 (-44,-17))	-57 (-83,-38 (-,-))	-29 (-3,-29)	
4	DAV	-15 (-14 (-51,14))	-12 (-55-5 (-51,12))	16 (-53,31-19 (-18,32))	-73 (-79,-70 (-,-))	-3 (-46,-3)	
	PAY	-59 (-67-60 (-66,-51))	-42 (-60,4-43 (-59,2))	-44 (-53-42 (-52,-27))	-46 (-57,-33 (-72,-37))	-29 (-29,-29)	
5	DAV	-27 (-25 (-53,12-13))	-46 (-44 (-64,-5-4))	-28 (-51,1-26 (-50,2))	-70 (-79,-52-60 (-72,-43))	-21 (-54,-21)	
	PAY	-56 (-64,-45-54 (-63,-44))	-51 (-62,-22-49 (-61,-23))	-34 (-52,-23-31 (-53,-21))	-54 (-75,-37-77,-29)	-28 (-28,-28)	
6	DAV	-37 (-38 (-55,-6))	-60 (-70,-48)	-40 (-39 (-54,-13-11))	-66 (-76,-46-63 (-72,-45))	-21 (-51,-21)	
	PAY	-50 (-60,-38-39)	-44 (-58,-7-42 (-59,-8))	-37 (-60,-17-39 (-62,-20))	-60 (-63 (-76,-39))	-24 (-24,-24)	
7	DAV	-45 (-58,-26)	-70 (-77,-59-71 (-78,-61))	-45 (-57,-27-26)	-67 (-77,-54-66 (-78,-52))	-37 (-55,-37)	
	PAY	-48 (-58,-35)	-60 (-67,-29-59 (-68,-30))	-59 (-61 (-71,-43-46))	-64 (-78,-42-77,-43)	-25 (-25,-25)	
8	DAV	-61 (-62 (-72,-49))	-77 (-84,-69-78 (-85,-70))	-62 (-75,-48)	-88 (-94,-80-90 (-95,-82))	-66 (-77,-66)	
	PAY	-64 (-63 (-76,-51))	-67 (-78,-58-66 (-79,-57))	-73 (-80,-66-79,-65)	-82 (-89,-72-71)	-48 (-62,-48)	

The relative shortwave cloud radiative effect ( $\text{SCE}_{\text{rel}}$ ) is calculated using Eq. 2. Table 2 summarizes the median of the  $\text{SCE}_{\text{rel}}$  and the corresponding interquartile range for cloud coverages of one to eight  $\text{oetas-oktas}$  and for the cloud classes for the two stations Davos and Payerne separately. The relative shortwave cloud radiative effect ( $\text{SCE}_{\text{rel}}$ ) is calculated using Eq. 2. The number of occurrence per cloud class and cloud fraction are shown in Table A1 and A2.

- 5 In Davos, the cloud type Cb-Ns, with -88-90 %, is the cloud type with the largest attenuation  $\text{SCE}_{\text{rel}}$  value for eight  $\text{oetas-oktas}$  for eight  $\text{oetas-oktas}$  cloud coverage. The second lowest  $\text{SCE}_{\text{rel}}$  value for eight  $\text{oetas-oktas}$  cloud coverage is observed for the cloud type Cu (-77-78 %), followed by Cc-Ac (-66-67 %). The cloud classes St-As (-62-%) and Sc (-61-both -62 %) are almost in the same range. The uncertainty ranges given as interquartile range are for a fully covered sky up to  $\pm 14$  %. Also here no statistical values have been calculated for the high-level cloud class Ci-Cs and a cloud coverage of 8  $\text{oetas-oktas}$  due to the same explanation as given in Section 3.2.1. However the median  $\text{SCE}_{\text{rel}}$  for Ci-Cs and 1 to 7  $\text{oetas-oktas}$  cloud coverage is in comparison to the low-level cloud classes clearly higher less negative with values between 01 and -9 %. In general, the median  $\text{SCE}_{\text{rel}}$  values become higher the smaller the cloud coverage is. This behaviour is obtained for all cloud classes except Cb-Ns, where the median  $\text{SCE}_{\text{rel}}$  values stay in the same range for all investigated cloud coverages.

- 15 In Payerne, a different order is observed in the lowest to the highest  $\text{SCE}_{\text{rel}}$  values for a cloud coverage of eight  $\text{oetas-oktas}$ . The cloud class with the lowest values, and thus the largest largest effect on SW radiation, is again Cb-Ns with -82 %, followed by St-As (-73 %), Cu (-67-66 %) and Sc (-64-63 %). The interquartile ranges are in a similar range as the ones for Davos. All these four cloud classes are low-level cloud types and also thicker clouds than the ones at a higher level. Therefore it is reasonable to

infer that these are the four cloud classes with the greatest effect on the downward shortwave radiation. For Payerne, a clearly ~~lower-less negative~~ median  $SCE_{rel}$  is observed for the mid-level cloud class Cc-Ac and a cloud coverage of eight ~~oetas (-48oktas~~ ~~(-47 %)~~ in comparison to low-level clouds. The highest median  $SCE_{rel}$  value for 8 ~~oetas-oktas~~ cloud coverage is observed for the high-level cloud class Ci-Cs (~~-28-29 %~~).

- 5 The differences in  $SCE_{rel}$  values between Davos and Payerne are for several cloud types and cloud coverages rather high (e.g. ~~32-33 %~~ for Cc-Ac and 3~~oetas)-One-~~oktas). An explanation for these larger differences, mainly for smaller cloud coverages, ~~might be is~~ the so-called cloud enhancement phenomenon, since the positive  $SCE_{rel}$  values might increase the median of  $SCE_{rel}$ . A cloud enhancement phenomenon describes an event where more downward shortwave radiation is measured at the surface under cloudy ~~condition-conditions~~ than expected under ~~clear-sky condition~~. ~~Multiple scattering at cloud particles lead~~
- 10 ~~to an increase of the diffuse irradiance part of the shortwave radiation~~. ~~cloud-free conditions~~. ~~Scattering at cloud edges lead to a focusing effect producing a local enhancement of the SW radiation~~.

~~For the calculation of the values in Table 2 different numbers of cases have been taken into account (see appendix Table A1 and A2). Analysing e.g. the images that belong to the group St-As and 2 oktas in more detail, leads to the result that at all the 14 images for this specific group in Payerne the sun is covered by a cloud, whereas in Davos, of the 58 images only in around~~

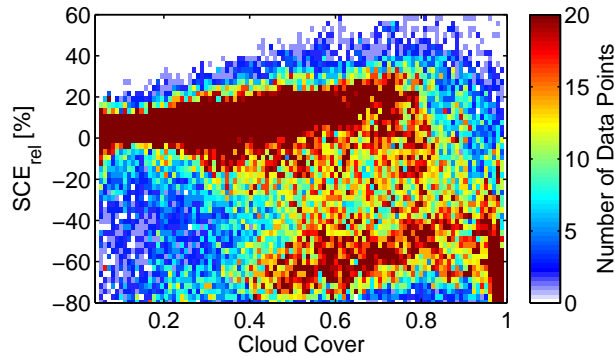
15 ~~20 % of the cases the sun is occulted and in the remaining 80 % the sun is visible. As further discussed in Section 3.3.2, this fact of visible or occulted sun can lead to a large difference in  $SCE_{rel}$  values. These larger differences in  $SCE_{rel}$  values between the two stations mainly occur when only a limited number of images is available. Therefore, some of the  $SCE_{rel}$  values have to be taken with caution.~~

Figure 4 shows a density plot of the dependence of  $SCE_{rel}$  on fractional cloud coverage in Davos for the mid-level cloud class Cc-Ac. Mainly ~~with-at~~ larger cloud coverages there is a ~~region-range~~ of higher densities of data points of  $SCE_{rel}$  values between -80 to -60 %. However, there is another stronger local maximum in the density distribution which shows positive  $SCE_{rel}$  values of up to 20 % at smaller cloud coverages. There are also some cases where the  $SCE_{rel}$  values reach up to 40 %. This enhancement of the downward shortwave radiation measured at the surface in the presence of clouds can also be detected in the low-level cloud classes.

- 25 If we define a cloud radiative enhancement with a  $SCE_{rel}$  of minimum +5 %, in Davos ~~74,857-69,941~~ cases of the ~~576,921-495,473~~ cloud cases are detected as cloud enhancement, thus in ~~1314 %~~ of the analysed cases. The ~~largest contribution stems from the~~ cloud class Cc-Ac ~~with-at~~ 32 % of the cases, ~~contributes most to this large number~~. ~~The cloud class with the second greatest contribution to cloud enhancement is Cu with~~ followed by Cu at 27 % followed by Se (20, Sc (21 %), St-As (110 %) and Ci-Cs (10 %). The cases of observed cloud enhancement due to the presence of Cb-Ns is negligibly small ~~with-at~~ 0.2 %.
- 30 Thus the mid-level cloud class Cc-Ac leads to most of the cases of cloud enhancement. However, checking for the cloud types that produce SCE values of more than 40 % leads to another order of contribution of different cloud classes.

In Davos, 2,621-238 cases (0.5 % of the cloud data) are observed with  $SCE_{rel}$  values of 40 % and above. Here the contribution of the two low-level cloud classes St-As (4743 %) and Sc (3740 %) is greater than the contribution of the mid-level cloud class Cc-Ac (1213 %). These are also the cloud types that mainly contribute to such high positive SCE values. The contributions of

35 Ci-Cs (2 %), Cu (1 %) and Cb-Ns (0.30.2 %) are negligibly small.



**Figure 4.** Density distribution of the dependence of  $SCE_{rel}$  on cloud coverage for Davos for mid-level clouds (Cc-Ac). The density colour distribution represents the number of data points.

- In Payerne, only in 8 in 10 % of the 126,148 cloud cases is 88,155 cloud cases a cloud enhancement of more than 5 %  $SCE_{rel}$  is observed. Also here, most of the cloud enhancement cases are Cc-Ac with 38 % contribution at 42 % of the cases, followed by Ci-Cs with 37 % - 30 % contribution. Cu only make makes a contribution of 18 19 % to the total 9,528 8,793 cases of cloud enhancement greater than 5 %  $SCE_{rel}$ . In 78 % of the cloud enhancement cases in Payerne a Sc cloud is responsible. The
- 5 number of cloud enhancement cases for the cloud classes Cb-Ns (0.71 %) and St-As (0.2 %) is negligibly small.
- A cloud enhancement of at least 40 %  $SCE_{rel}$  in Payerne is detected only for 412 281 cases in total in the studied time period. More than half of these 412 281 cases are Cc-Ac (58 62 %), followed by Cu (18 Sc (19 %)) and Se (13 Cu (9 %)). Only a few cases are Ci-Cs (7 Cb-Ns (6 %)) and Cb-Ns (3 Ci-Cs (4 %)). For St-As clouds there is no case observed with a cloud enhancement of more than 40 %  $SCE_{rel}$ .
- 10 *Schade et al. (2007)* also showed that altocumulus is the cloud type that produces most of the downward solar cloud enhancement. They demonstrated that altocumulus clouds can be responsible for temporary enhancements of up to  $500 \text{ Wm}^{-2}$ . In our data, in Davos the maximum in cloud enhancement with Cc-Ac is a SCE value of  $477 \text{ Wm}^{-2}$  and in Payerne of 486 440  $\text{Wm}^{-2}$  under Ci-Cs conditions. *Schade et al. (2007)* show showed that the largest cloud enhancements can be registered at almost overcast situations. However, our data show a maximum in cloud enhancement cases for a fractional cloud coverage of 3 to 4 oktas
- 15 in Davos and 1 to 2 oktas to 3 oktas in Payerne.
- The manual analysis of the cloud camera images with cloud enhancement leads to the result that in most of the cases there is a low solar zenith angle. Additionally, it has been observed that in cloud enhancement cases the sun is either in the vicinity of the cloud or covered with a thin cloud layer.
- Several studies (e.g. Robinson, 1966; Schade et al., 2007; Thuillier et al., 2013; Calbo et al., 2017) show the influence of the magnitude of cloud enhancement events and its duration. To compare our results with these analyses about the duration of cloud enhancement events the resolution of 1 min images needs to be increased to the seconds range and will be subject of a subsequent study.
- 20

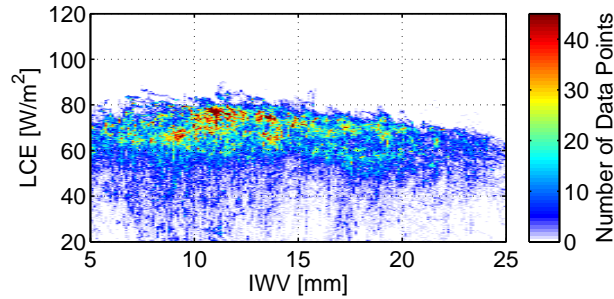
**Table 3.** The median and interquartile range of the total cloud radiative effect [ $Wm^{-2}$ ] per [oeta-okta](#) for the two stations Davos (DAV) and Payerne (PAY) and the six cloud classes stratocumulus (Sc), cumulus (Cu), stratus-altostratus (St-As), cumulonimbus-nimbostratus (Cb-Ns), cirrocumulus-altocumulus (Cc-Ac) and cirrus-cirrostratus (Ci-Cs).

cc [ <a href="#">oetaokta</a> ]	station	Sc [ $Wm^{-2}$ ]	Cu [ $Wm^{-2}$ ]	St-As [ $Wm^{-2}$ ]	Cb-Ns [ $Wm^{-2}$ ]
1	DAV	<a href="#">25-26</a> (-2,3839)	<a href="#">5</a> (-9,207 (-7,23)	- (-,-)	- (-,-)
	PAY	<a href="#">-32</a> (-103,37-14 (-78,24)	<a href="#">7</a> (-108,589 (-88,52)	<a href="#">-156</a> (-156,-156 (-,-)	- (-,-)
2	DAV	<a href="#">19</a> (-76,6520 (-80,66)	<a href="#">12</a> (-29,4217 (-22,45)	<a href="#">69</a> (4071 (30,84)	- (-,-)
	PAY	<a href="#">-26</a> (-159,66-21 (-156,59)	<a href="#">-46</a> (-228,90-42 (-217,87)	<a href="#">-100</a> (-224,-80-69 (-98,16)	<a href="#">-83</a> (-149,-37)
3	DAV	<a href="#">-6</a> (-186,86-5 (-197,88)	<a href="#">21</a> (-109,6835 (-106,73)	<a href="#">82</a> (44,12199 (51,129)	- (-,-)
	PAY	<a href="#">-197</a> (-278,-112-130 (-215,-78)	<a href="#">-115</a> (-293,94-113 (-289,95)	<a href="#">-78</a> (-142,-51-61 (-88,18)	<a href="#">-91</a> (-241,-41)
4	DAV	<a href="#">-40</a> (-201,93-42 (-216,97)	<a href="#">-40</a> (-214,91-17 (-239,99)	<a href="#">76</a> (-83,13487 (-64,137)	<a href="#">-58</a> (-95,-21)
	PAY	<a href="#">-192</a> (-268,-134-146 (-244,-91)	<a href="#">-198</a> (-359,55-360,51)	<a href="#">-118</a> (-223,-58-92 (-214,-41)	<a href="#">-91</a> (-173,-29)
5	DAV	<a href="#">-73</a> (-227,83-82 (-247,94)	<a href="#">-131</a> (-310,-5-166 (-360,-6)	<a href="#">-64</a> (-135,24-74 (-145,27)	<a href="#">-92</a> (-199,-58-36)
	PAY	<a href="#">-188</a> (-290,-116-154 (-270,-87)	<a href="#">-281</a> (-415,-119-282 (-419,-122)	<a href="#">-114</a> (-210,-40-97 (-189,-36)	<a href="#">-116</a> (-218,-54)
6	DAV	<a href="#">-119</a> (-287,8-139 (-308,4)	<a href="#">-187</a> (-353,-77-283 (-421,-143)	<a href="#">-94</a> (-169,-18)-105 (-186,-39-20)	<a href="#">-89</a> (-243,80-65)
	PAY	<a href="#">-170</a> (-273,-100-149 (-255,-80)	<a href="#">-257</a> (-364,-15-269 (-368,-29)	<a href="#">-135</a> (-191,-60-193,-67)	<a href="#">-138</a> (-262,-85)
7	DAV	<a href="#">-200</a> (-342,-69-218 (-352,-86)	<a href="#">-238</a> (-435,-124-343 (-507,-194)	<a href="#">-127</a> (-234,-51-145 (-258,-63)	<a href="#">-134</a> (-238,-60)
	PAY	<a href="#">-169</a> (-271,-100-155 (-262,-86)	<a href="#">-303</a> (-401,-101-292 (-398,-76)	<a href="#">-167</a> (-268,-121-157 (-240,-110)	<a href="#">-161</a> (-249,-91)
8	DAV	<a href="#">-323</a> (-455,-190-335 (-462,-210)	<a href="#">-310</a> (-504,-185-376 (-543,-247)	<a href="#">-225</a> (-377,-126-247 (-394,-145)	<a href="#">-210</a> (-356,-112)
	PAY	<a href="#">-255</a> (-381,-160-240 (-372,-141)	<a href="#">-466</a> (-560,-323-572,-322)	<a href="#">-263</a> (-399,-171-250 (-387,-159)	<a href="#">-226</a> (-365,-160)

### 3.2.3 Total Cloud Effect

The total cloud radiative effect (TCE) is calculated as the sum of the LCE and SCE (Eq. 1). The calculated median TCE values and the corresponding interquartile range for cloud coverages of one to eight [oetas-oktas](#) and the cloud classes for the two stations Davos and Payerne ~~separately are summarized~~ [are summarised](#) in Table 3 [separately](#). For the calculation of TCE, the absolute values of SCE are taken into account and Eq. 2 is not applied. The TCE values are mainly given to get an idea whether the SCE or the LCE is the prevailing contributor to the TCE during daytime.

During daytime, the SCE values are the main contribution to the TCE for all cloud classes and cloud coverages of 6 to 8 [oetas-oktas](#) and the two stations Davos and Payerne. For the low-level cloud type Cb-Ns, the TCE values are negative for all [oetas-oktas](#) cloud coverages. Thus during daytime the SCE is the main contributor to TCE for this cloud class. The smaller the cloud coverage is, the ~~more positive~~ [less negative](#) the TCE values are. This behaviour can be seen for all cloud types and both stations. Among other reasons, one reason for these positive values with smaller cloud coverages might be the cloud enhancement events as described in section 3.2.2. [Another reason might be the uncertainty in the cloud type detection algorithm as well as a larger uncertainty in SCE values the larger the SZA is.](#)



**Figure 5.** Dependence of LCE on integrated water vapour (IWV) for Davos and cloud coverage of 8  $\text{oetas-oktas}$  for low-level clouds (Sc, Cu, St-As, Cb-Ns) shown as a density plot.

### 3.3 Sensitivity Analysis

#### 3.3.1 Longwave Cloud Effect

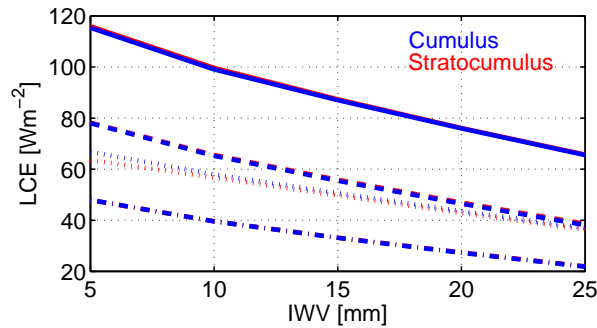
As [seen in Figure 3](#) described in [Section 3.2.1](#), the spread of the data within one  $\text{oeta-okta}$  cloud coverage is large. This large spread can be explained for example by the misclassification of the cloud type as well as by the uncertainty of the detection of cloud fraction of  $\pm 1 \text{oeta-okta}$  ([Wacker et al., 2015](#)). Additionally, other parameters are responsible for this uncertainty. Thus in a sensitivity analysis the influence of integrated water vapour (IWV) and cloud base height (CBH) is analysed.

Figure 5 shows the dependence of LCE on changes of IWV for all low-level clouds (Sc, Cu, St-As and Cb-Ns) and a cloud coverage of eight  $\text{oetas-oktas}$  for Davos. The low-level clouds have been taken together since on the one hand the LCE values for all the four low-level cloud classes are in a similar range and on the other hand there is considerable uncertainty in the distinguishing of the different cloud classes with increasing cloud coverage using the sky camera images. Figure 5 shows a slightly negative trend between the LCE and IWV. The higher the water vapour content in the atmosphere, the lower are the values of the LCE. Although the trend is statistically not significant, this negative trend is detected for different cloud classes, fractional cloud coverages and for the two stations Davos and Payerne.

The observed relationship between LCE and IWV was analysed by modelling a standard situation with the moderate resolution atmospheric transmission model MODTRAN5 ([Berk et al., 2005](#)). We assume a standard atmosphere profile for mid-latitude summer and winter separately with 50 altitude levels. We also assume no aerosol extinction throughout the atmosphere, due to its negligible influence on the longwave radiation ([Ramanathan et al., 2001](#); [di Sarra et al., 2011](#)). The default cloud parameters that have been taken for the model are for cumulus, a cloud thickness of 2.34 km (stratocumulus: 1.34 km), a cloud extinction coefficient at  $0.55 \mu\text{m}$  of  $92.6 \text{ km}^{-1}$  ( $38.7 \text{ km}^{-1}$ ) and a cloud liquid water vertical column density of  $1.6640 \text{ kg m}^{-2}$  ( $0.2165 \text{ kg m}^{-2}$ ) respectively. The input IWV values have been changed between 5 and 25 mm. The output of the model is shown in Figure 6 for cumulus (blue) and stratocumulus (red).

The mean values of the observed dependence of LCE on IWV (Figure 5) agree well with the mean values of the modelled dependence of the two aforementioned parameters LCE and IWV (Figure 6). Also the model shows that more water vapour





**Figure 6.** Dependence of LCE on integrated water vapour (IWV) modelled for cumulus (blue) and stratocumulus (red) clouds. Solid line: summer standard atmosphere (SSA) and cloud base height (CBH) of 1 km. Dotted line: SSA, CBH = 5 km. Dashed line: winter standard atmosphere (WSA), CBH = 1 km. Dash-dotted line: WSA, CBH = 5 km.

in the atmosphere results in lower LCE values for the two cloud types. The influence is smaller because in cases where there is more water vapour in the atmosphere, the cloud is shielded and the longwave radiation measured at the Earth's surface is partially coming from the water vapour and partially from the cloud itself. In the case of less IWV in the atmosphere, the influence of the cloud is greater and consequently also the LCE is higher. Cu and Sc show a similar behaviour in the model which might be explained by ~~the similar shape~~ similar microphysical characteristics of the two cloud types.

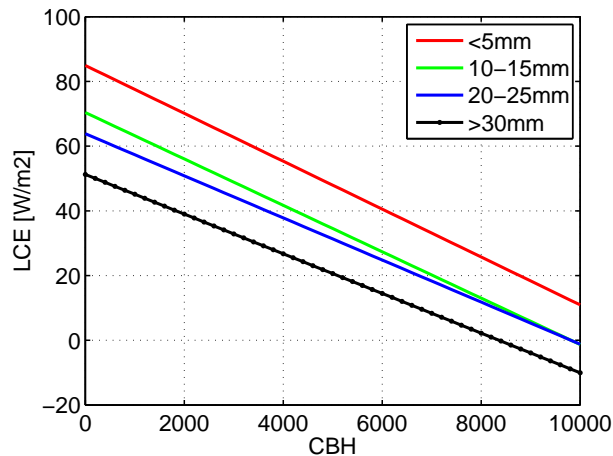
Another parameter which might explain the large spread in the LCE within one cloud cover range is the cloud base height (CBH). This analysis has only been performed for the data set in Payerne, because it is only at this location that we measure the CBH with a ceilometer. The observed mean dependence of LCE on ~~fractional cloud coverage and CBH~~ CBH and IWV is shown in Figure 7. ~~Different colours represent an interval of 2000 m in measured CBH (red: 0 – 2 km, to black: above~~ 12 km) ~~The colours represent different ranges of IWV.~~

Figure 7 shows that the lower the CBH, the higher is the LCE. This pattern can be explained by the fact that a lower CBH is a proxy for a higher cloud base temperature which in turn leads to higher thermal emission. The modelling of these cases with the radiative transfer model MODTRAN5 with the same standard conditions as explained in Section 3.3.1 confirms this assumption. The influence of CBH on downward longwave radiation has been analysed in more detail in (Viudez-Mora *et al.*, 2015). Figure 7 shows also that the more water vapour in the atmosphere, the lower the LCE.

Another important parameter in the LCE discussion for thin clouds is the optical depth of clouds (Viudez-Mora *et al.*, 2015). However, since no data of this parameter are available, it is not discussed in the current study.

### 3.3.2 Shortwave Cloud Effect

In ~~Figure 4~~ Section 3.2.2 it has been shown that mainly for small cloud coverages the majority of the cases show a  $SCE_{rel}$  value of around 0 %. In order to understand these values and the difference in the situation when the  $SCE_{rel}$  value is in a strong



**Figure 7.** Dependence of LCE on cloud ~~coverage~~ base height for Payerne and linear regression lines of the following ~~cloud-base-height-ranges of lowest-measured CBH~~ IWV ranges: red: ~~0 - 2000 m~~ < 5 mm, yellow: ~~2000 - 4000 m~~, green: ~~4000 - 6000 m~~ 10 - 15 mm, cyan: ~~6000 - 8000 m~~, blue: ~~8000 - 10000 m~~ 20 - 25 mm and black: ~~10000 m and above~~ > 30 mm.

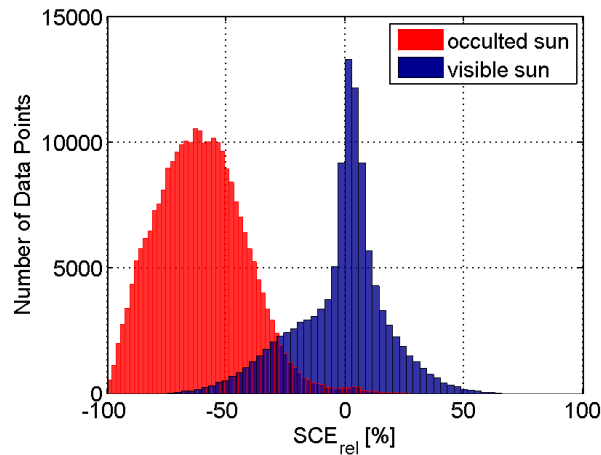
negative range we analysed the images to determine whether the sun is directly covered by a cloud or not. Whether the sun is ~~covered or uncovered~~ occulted or visible is decided on the basis of measured data of direct solar irradiance. In cases where the value of the direct solar irradiance measurement of  $120 \text{ W m}^{-2}$  per time step is exceeded, it is assumed that the sun is not covered by a cloud. This reference value of  $120 \text{ W m}^{-2}$  is defined by the World Meteorological Organization (CIMO, 2014).

- 5 Figure 8 shows the distribution of  $\text{SCE}_{\text{rel}}$  values of all data points in Davos for low-level clouds (Sc, Cu, St-As and Cb-Ns). This distribution shows two peaks, one at around  $\text{SCE}_{\text{rel}}$  values of 0 % and the other one at  $\text{SCE}_{\text{rel}}$  values of -65 %. If the cases are now divided into cases where the measured direct radiation value is below  $120 \text{ W m}^{-2}$  (red) and above this threshold (blue), the result is two separate histograms as shown in Figure 8. The red histogram shows the situations in which the cloud has a substantial effect on decreasing the measured shortwave radiation at the surface which results in a more negative  $\text{SCE}_{\text{rel}}$
- 10 value. The peak from the blue histogram is around zero to slightly positive values, ~~there~~. There the sun is uncovered and thus the cloud is not diminishing the direct radiation but rather increasing the diffuse radiation measured at the surface.

#### 4 Conclusions and Outlook

The current study ~~describes a time-series of analyses~~ the cloud radiative effect depending on cloud type and cloud fraction at two stations in Switzerland. ~~Furthermore, it explains the influence of integrated water vapour, the cloud base height and the coverage of the sun on the cloud radiative effect over a time period of three to five years.~~

~~Clouds increase the downward longwave radiation measured at the surface of the Earth and in general, decrease the downward~~



**Figure 8.** Distribution of  $SCE_{rel}$  values for Davos for low-level clouds (Sc, Cu, St-As, Cb-Ns). The measured direct SW radiation is below (red) or above (blue) a threshold of  $120 \text{ Wm}^{-2}$ .

shortwave radiation. Different cloud types have differing effects on the radiation measured on the Earth's surface. We have shown that low-level cloud types like cumulus, stratocumulus, stratus-altostratus and cumulonimbus-nimbostratus have with median values of  $5759 - 7172 \text{ Wm}^{-2}$  greater longwave cloud radiative effect values than for example mid-level clouds cirrocumulus-alto cumulus ( $37 - 49 \text{ Wm}^{-2}$ ). Our measurements show that most low-level cloud types have a longwave cloud effect at the surface in a similar range. The differences in the longwave cloud radiative effect between the two stations Davos and Payerne is for a cloud coverage of 8 octas up to 7 octas up to  $12 \text{ Wm}^{-2}$  and is becoming even larger (up to around  $25 \text{ Wm}^{-2}$ ) the smaller the fractional cloud coverage is. It has been shown Some of these differences might be affected by misclassifications of the cloud algorithm.

Our study confirmed, that the cloud base height and the fractional cloud coverage have an influence on the range of the LCE. The higher the cloud coverage, the greater the LCE and the lower the cloud base height, the larger the LCE. ~~The cloud base height can be taken as a proxy for cloud temperature and thermal emissivity.~~

~~However, not only cloud parameters like coverage and CBH have an influence, but also other atmospheric parameters. Our measurements show~~ We also showed that there is a negative dependence of the LCE on integrated water vapour. A similar trend was observed using radiative transfer modelling studies. ~~A similar trend was also demonstrated by Wacker et al. (2011) for stratus nebulosus.~~ We have shown that the LCE of not only low-level clouds but also of the mid-level cloud class cirrocumulus-alto cumulus show a dependence on cloud fraction, CBH and IWV, as well as by Wacker et al. (2011).

~~It has been shown, that the greater the cloud coverage is, the smaller are the differences of LCE values among cloud types. Thus, for a future study it might be enough to distinguish between low-, mid- and high-level clouds instead of cloud type. Also a time series of the SCE has been produced for the six cloud classes. It has been shown that also for the SCE the parameters cloud coverage and cloud type and thus cloud thickness influence the magnitude of the  $SCE_{rel}$ . Thus, low-level clouds~~ Low-level

clouds have a greater effect on the SCE (up to - ~~88~~90 % for Cb-Ns) than mid- (up to - 66 %) or high-level clouds (- 28 %). However, not only cloud parameters have an influence, but also whether the sun is ~~covered or not by a cloud. Our study shows that there~~visible or occulted. There are two different distributions depending on whether the measured direct SW radiation exceeds a threshold of  $120 \text{ Wm}^{-2}$  or not. ~~One of the distributions has a peak at around -60 %  $\text{SCE}_{\text{rel}}$  and the uncovered cases~~  
5 ~~have a peak at: one has its maximum at around - 65 % (occulted sun) and the other one~~around 0 %  $\text{SCE}_{\text{rel}}$  for Davos for the cloud type Ce-Ae. This difference is that high because the direct part of the shortwave radiation contributes most to the total shortwave radiation at the surface. Not only the mid-level cloud class shows these two peaks, but also all the low-level cloud classes Cu, Sc, St-As and Cb-Ns individually. For each of these low-level cloud classes the two peaks of the  $\text{SCE}_{\text{rel}}$  values are also in the same range. The differences in median  $\text{SCE}_{\text{rel}}$  values between Davos and Payerne are even larger than for the LCE,  
10 ~~with in general higher  $\text{SCE}_{\text{rel}}$  values for Payerne.~~(visible sun).

Our data show that in ~~13~~14 % and ~~8~~10 % of the cases in Davos and Payerne respectively a shortwave cloud radiative enhancement of at least 5 % is observed. We ~~showed~~show that Cc-Ac is the cloud type that is responsible for ~~around at least~~around at least one third of the cloud enhancement cases in Davos and Payerne. ~~Several studies (e.g. Robinson (1966); Schade et al. (2007); Thuillier et al. (2013); Call~~  
15 ~~show the influence of the magnitude of cloud enhancement events and its duration. To compare our results with these analyses about the duration of cloud enhancement events the resolution of 1 min images needs to be decreased to the seconds range and will be subject of a subsequent study.~~

In the current analysis, only one cloud type per cloud camera image is defined. A step forward would be to distinguish between different cloud types per image. This detection of different cloud types per image is already an intermediate step in our algorithm. At the current state the cloud type with most of the hits is determined. A further advance would be to not only get the  
20 most probable cloud type per image but also to obtain the different cloud types per image as output. Thereafter a more accurate analysis considering the influence of the cloud type on the cloud radiative effect would be possible.

~~So far we have only calculated the longwave, the shortwave and the total cloud radiative effect for daytime observations. Since the SCE is the larger effect during daytime, but is zero at nighttime, in order to calculate the total cloud radiative effect and to make the energy budget complete, also data for the nighttime have to be considered. In this direction a new instrument (To~~  
25 ~~further minimise the number of misclassifications, for a future study it might be enough to distinguish between low-, mid- and high-level clouds instead of cloud types. This would also increase the number of cases per cloud type and cloud fraction and might decrease the uncertainty of the cloud type detection algorithm. However, it would also decrease the variety in the cloud information.~~

~~Another step forward might be to combine different cloud detection instruments. A new observing system (thermal infrared cloud camera) has been developed in order to collect all-sky cloud information from day- and nighttime measurements. This increase of the data set to nighttime information is necessary for climate-monitoring applications.~~

30 ~~increase of the data set to nighttime information is necessary for climate-monitoring applications.~~

**Table A1.** Number of cases per okta for Davos and six cloud classes stratocumulus (Sc), cumulus (Cu), stratus-altostratus (St-As), cumulonimbus-nimbostratus (Cb-Ns), cirrocumulus-altocumulus (Cc-Ac) and cirrus-cirrostratus (Ci-Cs).

<u>cc [okta]</u>	<u>Sc</u>	<u>Cu</u>	<u>St-As</u>	<u>Cb-Ns</u>	<u>Cc-Ac</u>	<u>Ci-Cs</u>
<u>1</u>	<u>43</u>	<u>31,875</u>	<u>-</u>	<u>-</u>	<u>23,330</u>	<u>1,687</u>
<u>2</u>	<u>1,449</u>	<u>19,027</u>	<u>58</u>	<u>-</u>	<u>10,295</u>	<u>3,277</u>
<u>3</u>	<u>4,617</u>	<u>7,820</u>	<u>84</u>	<u>-</u>	<u>10,888</u>	<u>7,379</u>
<u>4</u>	<u>8,492</u>	<u>2,613</u>	<u>455</u>	<u>-</u>	<u>11,016</u>	<u>7,747</u>
<u>5</u>	<u>12,834</u>	<u>1,431</u>	<u>3,743</u>	<u>50</u>	<u>9,165</u>	<u>5,331</u>
<u>6</u>	<u>13,708</u>	<u>614</u>	<u>11,735</u>	<u>424</u>	<u>8,165</u>	<u>1,991</u>
<u>7</u>	<u>17,311</u>	<u>909</u>	<u>37,899</u>	<u>1,819</u>	<u>6,272</u>	<u>608</u>
<u>8</u>	<u>21,305</u>	<u>5,072</u>	<u>165,187</u>	<u>11,492</u>	<u>6,180</u>	<u>-</u>

**Table A2.** Number of cases per okta for Payerne and six cloud classes stratocumulus (Sc), cumulus (Cu), stratus-altostratus (St-As), cumulonimbus-nimbostratus (Cb-Ns), cirrocumulus-altocumulus (Cc-Ac) and cirrus-cirrostratus (Ci-Cs).

<u>cc [okta]</u>	<u>Sc</u>	<u>Cu</u>	<u>St-As</u>	<u>Cb-Ns</u>	<u>Cc-Ac</u>	<u>Ci-Cs</u>
<u>1</u>	<u>731</u>	<u>1,660</u>	<u>-</u>	<u>-</u>	<u>3,382</u>	<u>5,838</u>
<u>2</u>	<u>177</u>	<u>1,468</u>	<u>14</u>	<u>-</u>	<u>1,559</u>	<u>2,562</u>
<u>3</u>	<u>32</u>	<u>1,023</u>	<u>54</u>	<u>-</u>	<u>1,624</u>	<u>1,450</u>
<u>4</u>	<u>235</u>	<u>576</u>	<u>76</u>	<u>25</u>	<u>1,875</u>	<u>786</u>
<u>5</u>	<u>792</u>	<u>217</u>	<u>73</u>	<u>75</u>	<u>2,005</u>	<u>459</u>
<u>6</u>	<u>1,939</u>	<u>53</u>	<u>76</u>	<u>159</u>	<u>1,542</u>	<u>470</u>
<u>7</u>	<u>5,293</u>	<u>14</u>	<u>75</u>	<u>518</u>	<u>729</u>	<u>719</u>
<u>8</u>	<u>27,091</u>	<u>29</u>	<u>7,539</u>	<u>12,530</u>	<u>142</u>	<u>469</u>

## Appendix A: Appendix

*Competing interests.* The authors declare that they have no conflict of interest.

*Acknowledgements.* This research was carried out within the framework of the project A Comprehensive Radiation Flux Assessment (CRUX) financed by MeteoSwiss. Alexander Haelele from MeteoSwiss provided the ceilometer data. All data are available from the corre-

5 sponding author on request.

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