Answer to Anonymous Referee 2

The authors are grateful for the time and thought that Anonymous Referee 2 put into the review and comments regarding our paper. We incorporate most of those comments into our revised manuscript, which has led to substantial improvements. Detailed responses to all comments follow below. The original comments from Anonymous Referee 2 are in italics and our responses as well as changes in the manuscript in plain text.

In this article, an algorithm is developed (FLICA) to retrieve cirrus cloud properties based on lidar measurements at three stations in Europe. Using these retrievals, a cirrus climatology and cirrus radiative forcing in each station are presented. Differences of cirrus at three locations are discussed. Subvisual, thin and opaque cirrus are analyzed. Results are also compared to previous studies, and the differences with results by Chen et al. (2000) are particularly emphasized. This paper is generally completed and well written. My main comments/questions relate to the section of comparisons with previous studies, and methods to calculate ice cloud radiative forcing.

Specific comments.

1. Title of this study, 'Radiative properties of …', since a climatology of cirrus is also an important part of this study, is it better to say ' Climatological and radiative properties of…'

<u>Response:</u>

This is an excellent idea. We have changed the title accordingly.

2. Aerosols:
How the algorithm distinguish aerosols and cirrus in this article? Cirrus clouds with small optical depth (e.g. tau<0.001) look more like aerosols?

<u>Response:</u>

FLICA uses a criterion for depolarization to help preventing that aerosols are classified as cirrus clouds. As we have already stated in the manuscript, to ensure that the highest cirrus clouds observed above Jungfraujoch were not volcanic ash particles (which would also depolarize the backscattered light), we have examined satellite measurements and found no indication for volcanic influence. Furthermore, our temperature threshold of -38°C excludes most aerosols because most aerosol layers are located below 6 km. Even though this combination of criteria might not be perfect, we believe that cirrus clouds are clearly distinguished from aerosols in the very most cases.

<u>Changes in the manuscript:</u>

No changes have been applied to the manuscript.

3. Page 15. Line 5. How do you make sure such a small optical depth (< 5x10-4) is not resulted from noises or from aerosols?

<u>Response:</u>

Areas of 3×3 pixels are examined, with the pixel to be checked for cloudiness in the center. At least 8 of the 9 examined pixels have to have a volume depolarization larger than 0.007(0.006) and a BSR larger than 1.08(1.03) for day(night)-time measurements. As mentioned above, the output of the cloud detection scheme was in addition visually inspected for individual days and was found not to show any apparent artifacts (such as aerosol layers or noise).

Changes in the manuscript:

No changes have been applied to the manuscript.

4. Page 17, line 25, The mean solar zenith angle for three locations is 60°. However, JUL and JFJ are about 4 degrees latitude off, and thus the mean length of daytime (mean SZA) in the two locations should also be quite different, which will cause radiative flux biases. Have you ever check the differences?

Response:

Thank you for pointing out this issue. The differences in latitude between the three stations have two consequences. First, the length of daytime is different for the stations. This value is however taken directly from the measurements (see line 28 on page 19). Second, the differences in the solar angle affect the incident radiation. The overall difference in the incident solar radiation is 6%. Nevertheless, the radiation model of Corti & Peter has an accuracy that "is typically better than 20% when comparing with the accurate results from the Fu and Liou (1992, 1993) radiative transfer model", thus we consider this error to be of minor relevance for the model results. In addition, addressing as well item 5 below, we want to examine the radiative properties of the cirrus clouds as a function of optical depth and temperature under otherwise comparable conditions.

Changes in the manuscript:

No changes have been applied to the manuscript.

5. Page 17, line 25, An albedo of 0.3 is globally average planetary albedo. The mean surface albedo is about 0.15 (Kiehl and Trenberth, 1997). Also, surface albedo varies from different locations and in different seasons. In particular, JFJ is located at a high altitude and has a cold climate. How many days of this location will be covered by snow in a year? Surface albedo covered by snow is large (> 50%).

Response:

Jungfraujoch lies on top of a glacier and is all year covered by snow. We have made calculations using albedos of snow (0.65) for Jungfraujoch. If we use a snow-albedo, the radiative effect of the cirrus clouds disappear as all radiation is scattered back by the snow surface. As already mentioned in reply to item Ulrich Schumann, we chose a value of 0.3 to demonstrate the global average effect of cirrus clouds such as those detected above the three locations.

Changes in the manuscript:

No changes have been applied to the manuscript.

6. Page 17. Line 29: The extinction coefficient can be derived from radar backscattering and then optical depth is obtained as shown in equation 7 in this paper. The tau values are used to calculate ice cloud radiative effect. Have you look at how different cirrus radiative effect *will be if the extinction coefficient profile is used? The profiles characterize the vertical details of a cloud, which are more accurate to produce radiative fluxes (Chen 2000).*

Response:

For this work, we have chosen to focus on the model of Corti and Peter, which uses the optical depth and cloud temperature as input (besides the surface albedo. This model has an accuracy better than 20% as compared to the model of Fu and Liou. We added this information to the manuscript.

Sentence added to the manuscript on page 19, line 13-14 in blue:

The accuracy of Corti and Peter (2009) is better than 20 % in comparison with the Fu-Liou model.

7. How the asymmetric factor and single-scattering albedo of the clouds are determined?

Response:

The asymmetry factor determines the forward scattering of a cloud and thus also the reflectivity. The reflectivity is approximated depending on optical depth and a fixed value as a result of radiative transfer calculations using the Fu-Liou code. For more detail see Corti and Peter, 2009. p. 5755.

Our value for single scattering albedo is ω_0 = 0.55, which is a realistic estimate for longwave radiation (Stephens et al., 1990). The exact value is not decisive for our parameterization, since variations of 10 % in this parameter increases the mean error of CRF_{LW} in comparision with radiative transfer calculations only by about 1%. Again, for more detail see Corti and Peter, 2009. p. 5754.

Changes in the manuscript:

No changes have been applied to the manuscript.

8. Section 4.2, Comparisons with previous results

Several paragraphs in Section 4.2 describe how results in this study differ from Chen et al. 2000. I doubt the way of comparisons for the following reasons. 1) different definitions of cirrus as stated in this article, and thus radiative forcing of cirrus is different. 2) different resolutions, it is 280 km resolution in Chen et al. 2000, while in this study, lidar has a small field of view (1.5 mrad by 0.3 mrad); 3) time period is very different (four days in Chen's study and five years in this study); 4) More importantly, although the three stations are located around 50°N, comparing ice cloud properties to zonally average values at 50°N provided by Chen et al.2000 is unreasonable since ice clouds vary significantly around 50° (e.g. Sassen et al. 2008). I'm confused why this section is necessary. Do you want to check that your results are correct? If so, why not compare to CERES fluxes? Could you justify the reasons why such comparison is necessary in this study?

Response:

We wanted to compare our data with similar measurements. There are only few publications assessing the radiative effect of mid-latitude cirrus clouds and the paper by Chen et al. is one of them. We are aware (and mention extensively in section 4.2) that it is very difficult to compare our and Chen's results due to the reasons you mention. Concerning a comparison with CERES fluxes, we are not aware of a publication discussing cloud radiative forcings derived from the CERES data for mid-latitude cirrus. Conversely, establishing CRF for cirrus from CERES data is beyond the scope of the present investigation.

Changes in the manuscript:

No changes have been applied to the manuscript.

Besides Chen et al. 2000, this article also lists a series of related studies in Section 4.2 (page 21, lines9-30). It may be better to move these paragraphs to introduction.

Response:

After consultation with all co-authors we decided to keep the information at its origin position in the article as we think it is most suitable where it is.

9. Page 25, line 11: ' cirrus clouds, which remain undetected by satellites (requiring typically tau>0.2)…', CALIPSO lidar can detect ice clouds with tau< 0.2. It would be better to revise the satellites as ' passive remote sensing'. It'll be better if a related reference added after tau> 0.2.

Response:

We agree and have adapted this in the manuscript, reading now "passive remote-sensing satellites".

Changes in the manuscript on page 28, line 4 in blue:

"by passive remote-sensing satellites"