Reply to comments of Reviewer #3:

Thank you for the time and efforts you have spent on reviewing our manuscript; this is truly appreciated. Based on your comments (copied below) we reply with a point-by-point discussion of your concerns (italic, in blue). We also include a detailed description of how we have considered your suggestions in the revised manuscript version.

General remark: Because the calibration of radiation sensors in the laboratory and the required transfer of the calibration into the field by secondary standards cause additional uncertainties of the measured irradiances and the derived layer properties, we decided to use an in-flight calibration technique (instead of relying on the laboratory calibration and its uncertain transfer to the field) for the irradiance measurements. The in-flight calibration method was already successfully applied in previous field campaigns. It is based on radiative transfer simulations of the downward irradiance in clearly cloudless sky conditions at high altitudes. In this case the measurements are only slightly affected by the atmospheric layer above the sensor and the measurements can be adjusted directly to the simulations. This in-flight calibration approach is then transferred to all radiation sensors installed in the aircraft and AIRTOSS. We have applied this calibration and concentrate on a specific measurement of the flight of 30 August 2013, which is more appropriate than the example discussed in the previous manuscript version. This specific case is characterized by a relatively high optical thickness of the cirrus layer taken into account that the vertical separation between the aircraft and AIRTOSS is 200 meters only. Another criterion for selecting this measurement case was that there was no additional cirrus above or below the layer enclosed by the aircraft and AIRTOSS. So we have chosen a case most suitable to derive optical layer properties of cirrus.

Reviewer #3: The measurement of cloud layers properties from collocated aircraft goes back several decades and lead to the “anomalous absorption” problem. Cloud flux divergence is a difficult measurement to make under the best circumstances. The inhomogeneous and often optically thin cirrus clouds makes them especially difficult. The authors correctly point out that collocated aircraft should, in theory, lead to better estimates of cloud layer properties such as absorptance (absorptivity). But the collocation of aircraft is no guarantee that it will. The problem of horizontal flux divergence still exists and substantial errors in the results of airborne flux divergence measurements are common/expected (e.g. Schmidt et al., 2010, Marshak et al., 1999). Other authors have proposed methods to ameliorate the effects of horizontal flux divergence (Cox and Ackerman and Cox, 1981, Marshak et al., 1999), and these techniques have lead to plausible results (Kindel et al., 2011).
Reply: *Thanks for this compressed summary of the problem, of course we agree. In case of optically thin cirrus the question of the importance of horizontal photon transport was one of the motivations for our study.*

Reviewer #3: It is clear from the results shown in this paper that despite the collocation of the spectral irradiance measurements, there are significant problems with the measurements that are not addressed in the paper. See for instance, Figure 7. The absorptivity, shown in green, exhibits more than 10% absorption in the visible and then decreases as it approaches 1000 nm at which time it becomes negative (non-physical). The absorption of ice cloud (and liquid water cloud) is zero (single-scattering albedo is 1) for the visible wavelengths regardless of the ice particle size or shape (see Figure 7(c)). The absorption begins to decrease at the point it should begin to increase in the near-infrared. The single-scattering albedo drops below one in the near-infrared and some absorption is expected. No discussion of the significant absorption in the visible is given in the text, nor are the effects of horizontal flux divergence or any attempt to compensate for them. There is one sentence remarking on the effect of horizontal photon transport in section 4.2.2. It explains lower absorptivity in the 1000 to 1500 nm range and a result of horizontal photon transport in the cloud layer. I cannot make sense of what is meant here. Why only 1000 to 1500 nm? In the cirrus layer or the low cloud layer or both?

__Reply:__ We carefully screened the entire data set and selected a new measurement case for discussion in this manuscript. The modified and new measurement example does not show these anomalous values anymore.

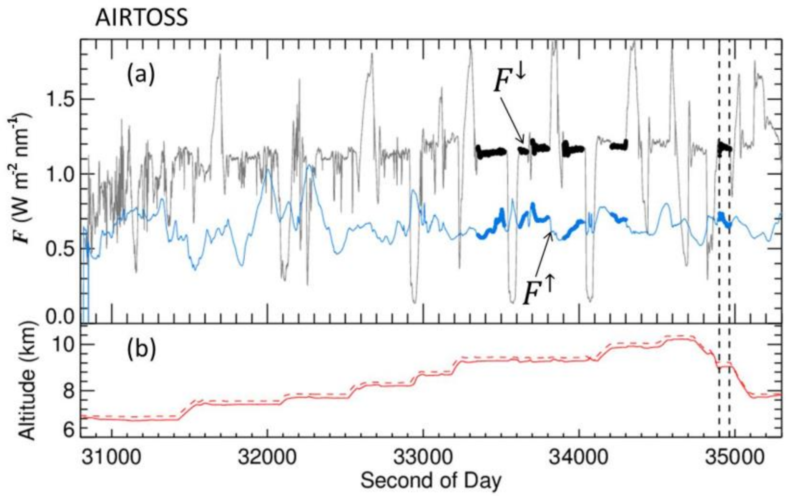

Fig.6: (a) Time series of downward (gray) and upward (light blue) irradiance F ($Wm^{-2}\ nm^{-1}$) measured on AIRTOSS at one wavelength (550 nm) from the flight of 30 August 2013. The thickened line periods mark the measuring points at straight flight legs. The red lines in (b) show the altitude of AIRTOSS (solid) and Learjet (dashed). The vertical dashed line marks the measurement example in Fig. 2.

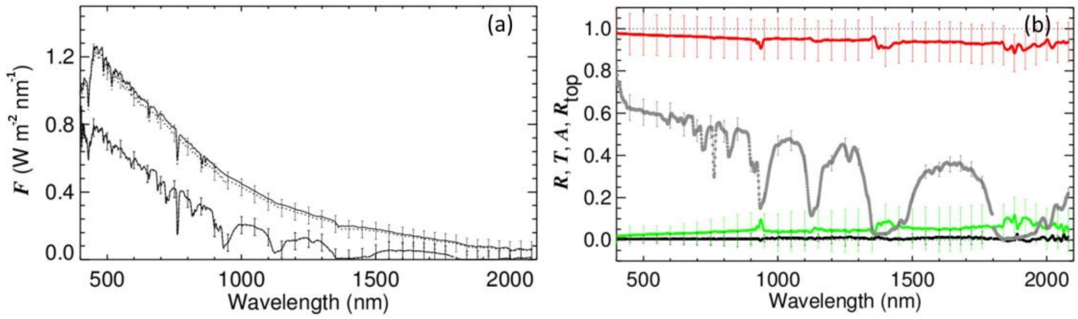

Fig.7: (a) shows measured spectral downward and upward irradiance F from the aircraft above the cloud layer (solid lines) and AIRTOSS below the cloud layer (dotted lines) at the time, indicated by the vertical dashed line in Fig 1. Ftop is simulated. (b) shows spectral reflectivity (black), transmissivity (red), absorptivity (green), and cloud top albedo (gray) according to irradiance in (a). The vertical bars indicate the systematic errors due to measurement uncertainties.

This measurement example was chosen due to the higher optical thickness, and because of the low vertical extent, which enables to measure above and below this cirrus layer.

__Reviewer #3__: The measurement of reflectivity has an unusual shape as well. The reflectance goes up in the near infrared (Figure 10(b)). This is not what is expected nor is it what is demonstrated in the modeling. Reflectance goes down in the near infrared for a cloud over a dark surface (in this case water). The authors, in Equation 4, point out that the sum of T, R, and A must equal one (i.e. energy conservation). Why not plot T+R+A?
__Reply:__ As the cloud optical layer properties of the investigated cirrus are derived by using the equations (1)-(3) including the measured upward and downward irradiances, equation (4) shows that the sum of the three quantities always holds unity. This is a matter of definition, see equation (4). This is valid for both, measurements and simulations.

Reviewer #3: This would be a good test of the validity of the measurements. This would also be a good test of the modeling results as well, which also contain results that seem to be incorrect. For instance, in Figure 12(b), R becomes negative between 1500 to 1800 nm and 2000 to 2200 nm. What is negative reflectivity? Additionally, in Figure 12(b) the water vapor absorption bands (940, 1140, 1400, and 1900 nm) have greater reflectivity than the surrounding window regions. How is this possible?
Reply: *Please see the comments above. The new measurement example does not show these anomalous values anymore.*

Reviewer #3: The modeled albedo (Figure 12(d), spectrum in black) Rtop increases with wavelength; the albedo is greater in near-infrared than in the visible. Again, how is this possible?
Reply: *The modified and new measurement example does not show these anomalous values anymore.*

Reviewer #3: The measurement of Rtop makes more sense than the model in this case. The albedo decreases in the infrared. Additionally, it would be very useful to list the optical thickness and effective radius along with the shape used in all the calculations given in this work.
Reply: *Thank you for the advice! A table with the listed optical thicknesses for the different ice crystal shapes can be found in the paper, now.*

Table 1: Shown are the optical thicknesses for a cirrus between 6.7 km and 8.5 km altitude assuming different ice crystal shapes for Approach I (constant number size distribution) and Approach II (constant ice water content).

	Approach I	Approach II
Droxtal	1.49	2.68
Solid Column	1.50	3.20
Column 8 Elements	0.77	7.45
Plate	1.15	4.44
Plate 10 Elements	0.54	15.4
Hollow Bullet Rosette	0.97	9.52
Baum	1.00	5.09

Reviewer #3: The differences are substantial between the shapes, but it is not clear what the differences are in the optical thicknesses and effective radii. There are aspects of the measurement technique that are unclear and confusing. The measurement, as I understand it, was made with the aircraft above the cloud layer and the AIRTOSS below the cloud layer (see Figure 3.) This is coupled with a relatively minor offset in time (5 or 6 seconds) because the AIRTOSS trails the aircraft. In Figure 7 the shaded gray area delineates the cloud vertical extent. I estimate the thickness to be about 1.7 km. In the section describing the time correction the vertical extent of the AIRTOSS from the aircraft is given as 914 meters. This, even if flown directly beneath the aircraft, is not long enough to span the thickness of the cirrus layer.
Reply: *You are correct, this has not been described adequately in the manuscript. As the vertical difference between the two platforms is not more than about 200 m the investigated cloud layer, shown by the measurements in Fig. (7) and (8), represents a part of the complete cirrus layer. The sketch in Fig. (3) shows the principle of collecting measurements when a cloud layer is in between the two platforms.*

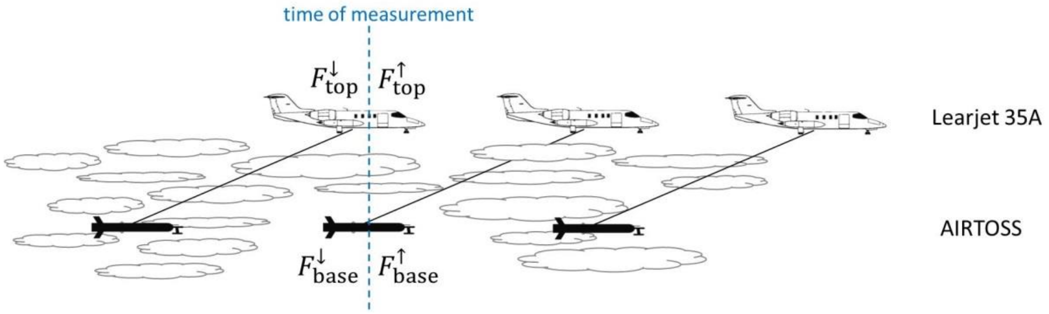

Fig. 3: Schematic sketch of measurement setup to measure collocated upward and downward irradiance at two altitudes.

Reviewer #3: Additionally, in Figure 8, the Fdown from above the cloud layer is simulated not from the aircraft measurement. What is the point of using a model Fdown if a measurement was made?
Reply: *There were some temporal problems with the active levelling of the optical inlet measuring the downward irradiance on the Learjet during the campaign. Therefore we have replaced the measured downward irradiances (Learjet) by respective simulations whenever the leveling platform did not work appropriately. That is well justified in case of measurements at high altitudes with no cirrus above. We have proven in numerous field campaigns that for such cases the horizontally levelled measurements are accurately described by simulations. This is not in contradiction with the general need to apply levelling platforms for measurements under more complicated cloud situations, which we avoided in the manuscript by carefully choosing a case with no cirrus above the high measurement altitude.*

Reviewer #3: This would help to offset any radiometric calibration errors if all of the spectrometers were calibrated to the same radiometric source. Why not plot the aircraft and the AIRTOSS altitude on Figure 7(b)?
Reply: *Thank you for the good advice. Please, see the two altitude curves in Fig. (1).*

Reviewer #3: It would make it clear exactly where the aircraft and AIRTOSS were during the measurement period. If the measurements were not truly collocated, that is, aircraft measured irradiances above the cloud layer, and AIRTOSS measurements below the cloud layer, measured within five or six seconds of each other, it is difficult to see how this technique differs from a single aircraft experiment.
Reply: *There are several advantages to use the setup of aircraft and towed platform in contrast to a single aircraft measurement. Firstly, in the altitude range of cirrus clouds the wind velocities are high resulting in a fast passage of the cirrus out of the measurement area. Furthermore, they might change their microphysical and optical properties during the time the second measurement can be performed. Secondly, it is hard, or nearly impossible, to assure that the field of view during the second measurement is the same as for the first.*
So, the setup of Learjet and AIRTOSS ensures a maximum temporal difference of 5 to 6 seconds between the measurement at two different altitudes and both devices investigate the same spatial sectors being crucial for investigating the cloud layer in between.

Reviewer #3: The irradiance (Fbase up) reported for Time I (Figure 8(a)) the "no low-level cloud" is far too high to be an irradiance spectrum over cloudless ocean. These spectra clearly include the effects of low-level cloud. Over cloudless ocean, the peak of the upwelling irradiance in the near infrared is rarely, if ever, over 0.1 (W m-2 nm-1). Was this period of "no" low level cloud selected on the irradiance values alone or was it confirmed with ancillary data such as aircraft video?

Reply: *The new measurement example, as well as the complete measurement flight of 30 August, was influenced by a low – level cloud layer. This is supported by a video (recorded out of the cockpit) as well as synoptic forecast and MODIS data (see Fig. 4).*

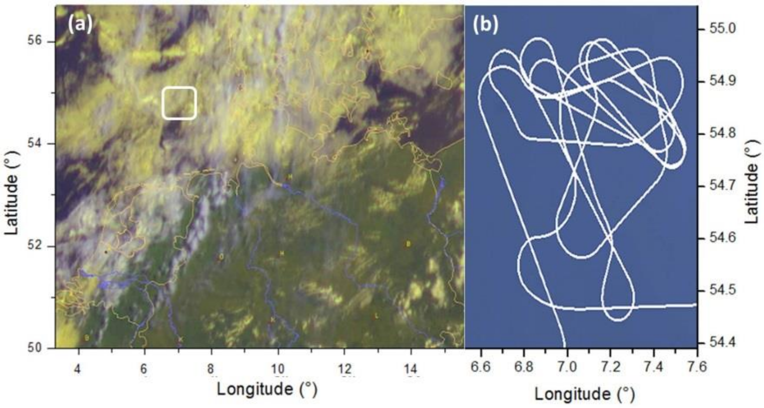

Fig. 4: (a) Composite satellite image of the cloud situation on 30 August 2013 at 9:45 UTC showing cirrus (white) above yellow colored lower water clouds (DeutscherWetterdienst / EUMETSAT).

Picture from out of the cockpit of the Learjet, showing the cloud situation during the flight. The low–level cloud layer is visible with the cirrus cloud above.

Reviewer #3: It is not clear to me why this is called a feasibility study. Generally, a feasibility study in this context is meant to denote analysis undertaken to demonstrate whether a particular measurement is likely to be successful given the characteristics of the problem and the performance of an instrument/measurement technique. This is not a feasibility study, as I understand it. Measurements were made and the results are in poor agreement with modeling results and what is generally expected from basic cloud and atmospheric radiative transfer.

Reply: *Thank you for your advice! The manuscript title has been changed to "Spectral Optical Layer Properties of Cirrus from Collocated Airborne Measurements and Simulations".*