Response to Referee #2

The authors are sincerely grateful for the careful reading of the work. Your comments are very useful and will be taken into account when finalizing the text. Some of them, especially concerning the refinement of the drawings, required a long time. I will now respond to comments and add a revised text.

1. “Clouds of Upper Layers” in the title sounds strange. It would be better to replace it with “ice clouds” or “clouds in the upper troposphere”. Why you mention “upper layers”, you can as well observe clouds and ice clouds in lower parts of the troposphere. In general, I would omit the term “upper layers” throughout the whole manuscript. It can be replaced by “upper troposphere”.

I agree that the term “layer” is incorrect and very unfortunate. The terms "High-level" or "Mid-level clouds" are recommended by the International Cloud Atlas. I will try to use these terms in the manuscript and "ice clouds" in the title.

2. I miss a bit the discussion about the atmospheric relevance of your findings. What does the additional information we get by scanning through the cirrus help us in characterizing cirrus clouds? It is interesting to know, if a cirrus cloud consists of orientated or randomly orientated ice crystals. In the introduction you mention the sun glare. You could add discussion about the atmospheric implications of your findings. This will further underline the importance of your newly developed lidar system.

I can only say that both the shape of the crystalline particles and the presence of their orientation are determined by complex meteorological processes in the cloud. Therefore, the study of the orientation of crystalline particles provides significant information about these processes. However, the authors are not experts in the field of cloud physics. So I would not like to open a big discussion on this issue

*Revised text, Line 75.* The optical properties of ice clouds, including their effect on the radiation balance, are determined by both the microphysical properties of crystalline particles and the presence of their orientation. These properties are in turn determined by complex meteorological processes in the clouds. Therefore, the study of the orientation of crystalline particles provides significant information about these processes.

3. You give an exponential parameterization (equation 1). But the reader finds nowhere in the manuscript any parameters for this fit. You should definitely provide some fitting parameters for your curves (A, alpha_0, w).

It's not quite so.

*Line 317. (in the revised text)* For Fig. 10a $w$=42 arc minutes, for Fig. 10b $w$=82′.

*Line 330.* For all measurements the value $w$ is within 40-160 arc minutes.

Values $w$ are indicated in *Fig. 11* with squares. (Fig 11 and other figures is corrected)

*Line 330.* The shift $\alpha_0$ of the curve maximum from 0° is less than 2 minutes, (a symbol "$\alpha_0$" is added into the text).

The absolute values $A$ and $I_0$ are not interesting, because they are determined by the sensitivity of photodetectors. The ratio $I(0°)/I_0$ is indicated in Fig. 11.

4. To discuss the differences in the cirrus observations, it would be extremely helpful to provide some more information about the cirrus cloud. Firstly, the temperature profile within the cirrus. You show some radiosonde data in Fig. 7+8, but you don’t use this information in the text. At which temperature do you observe the two cirrus clouds on 6 April 2018? At colder temperatures, the ice crystals may have different properties. To improve the Figures, I would show a temperature profile exactly for the same height range (6 – 10 and 7.5 – 12 km) as in Fig. 7a+b and 8a+b instead of the shown diagram. And please add the time of radiosonde launch.
Secondly, the different exponential behaviors in Fig. 11 are related to different cirrus clouds. What additional information do you have about these cirrus clouds? Cloud height? Cloud thickness? Cloud top temperature? Temperature profile within the cloud? Age of the cirrus cloud? Formation process? May this information help to explain the different behavior?

5. Where did you perform the measurements? In Tomsk. Can you add some coordinates?

How far was the radiosonde station?
6. How did you select the measurements in Fig. 11 (ln 280)? Which criteria did you use?

I agree that radiosonde data should be presented more clearly. But we do not know the meteorological parameters of each layer inside the cloud. It is because of the distant location of the station and the rare launches of probes (once every twelve hours). Clouds change their structure in 5-10 minutes. No radiosondes can provide such volatile information. Then, our previous observations (Balin 2011) showed that mirror layers may exist in both the lower and upper parts of the cloud. So the layer height inside the cloud also does not correlate with its polarization. The selection of cloud portions presented in the figure 11 is rather random and subjective. The only requirement is: these portions must have a pronounced dependence on the tilt angle, and there is no signal overflow when the lidar is oriented to zenith (Sect. 4.2). Today I don't know how to proceed and present the data (polarization) across all cloud height.
*Revised lines in the text*
*Line 252.* Measurements were made in Tomsk (56°28'N, 85°E)
*Line 270.* Radiozonde sounding was carried out at Novosibirsk station, about 250 km from Tomsk to SW, two records were made at 07:00 and 19:00 LST. Of course, due to the distant location of the station and the rare launches of probes (once every twelve hours) these data do not describe the fine structure of the ice cloud.
*Line 275.* A high-level cloud consists of two layers. The thin bottom layer (6600-7000 m) has a temperature minus 26-31°C, the top layer (7800-9800 m) temperature is 37-52°C below zero
*Line 287.* A cirrus cloud with a complex structure extends in a layer of 8 - 11.7 km. The temperature in the cloud varies from -34°C to -60°C.
*Line 325.* Figure 11 gives some selected dependences of intensity angle distributions for component $I_{\parallel}$. We did not find any correlation of the distribution parameters ($A$, $I_0$, $w$) with the height of the selected area inside the cloud. So the selection of cloud portions presented in Fig. 11 is rather subjective. The only requirement is: these portions must have a pronounced dependence on the tilt angle, and there is no signal overflow when the lidar is oriented to zenith.

7. The symbols â´L˘e and âŁ˘e correspond to parallel and orthogonal normally linked to linear polarization. Circular polarization is right handed or left handed or more general it can be described as co-polar and cross-polar. Or at least mark the intensity as a circular polarized component whenever it is used to not confuse the reader with the linear polarization.
In general, you should be more careful in distinguishing the linear and circular depolarization ratio throughout the text (often it is just stated "depolarization ratio").
I suppose that left-handed and right-handed circular polarizations are orthogonal, too. But I agree that the use of a symbol $I_{\perp}$ may be unreasonable for circular polarization. So I will use $I_{co}$ and $I_{cros}$ in the text and figures. Then the depolarization ratio is equal to $I_{cros}/I_{co}$ both for linear and circular polarization.

8. The paragraph line 286-292 describing the relation of circular and linear polarization should be placed earlier. The same holds for the information in line 300-303. Till these lines, it remained unclear how you deal with two wavelengths and a quarter wave plate. This has to be mentioned when describing Fig. 4.
Lines 300-303 are now in Sect.2. Lines 286-292 are shifted to the beginning of Sect. 4.1.
Revised text
*Line 111.* We have two sets of quarter-wave plates. One set is designed for 532 nm, another set for 1064 nm. For the wavelength of installed plates (below are the results only for installed 1064 nm plates) we can investigate both linear and circular polarizations. For the second wavelength (532 nm) polarization state when turning 45 degrees is not determined. However, in the position where the axis of the rotating phase plate coincides with the plane of polarization of the transmitter, the radiation remains linearly polarized for any wavelength. So the measurements for the wavelength of $\lambda$ = 532 nm were carried out only for linear polarization of radiation. Of

course, in our lidar we can use a quarter-wave plates for 532 nm if such experiments were planned.

9, 10 Figures and captions.

All figures and captions are updated

16. ln 89 "to evaluate some elements of BSPM" Which elements? Be more precise

*Line 94.* ...that makes it possible to detect the deviations of BSPM from diagonal shape (Balin et al., 2011).

18. ln 94 "PP1 with the phase shift of 20 wavelengths is used for _ = 532 nm, and 9.5 wavelengths for _ = 1064 nm." What do you mean by this?

*Line 98.* For coincidence of the polarization planes, the phase plate *PP1* with the phase shift of 20 wavelengths for λ = 532 nm and 9.5 wavelengths for λ = 1064 nm is installed. The rotation of this plate causes the rotation of the polarization plane for 1064 nm but does not affect the polarization of 532 nm.

21. ln 146 Where do you get this value from?

*Line 160.* Accuracy of installation angle is θ=34′=0.0125 rad. ... *θ* is a small setting angle error. $\Delta\delta=\theta^2$=0.000156≈0.016%

22. ln 148-150: 45_ * 0.68 ms /0.3_ = 102 ms Using the information you provided, the quarter wave plate would need 102 ms to turn by 45_. That would be too slow for a laser repetition rate of 10 Hz. Maybe you just have to report one more significant digit for time?

I think, 102 ms is not much different from 100 ms need for 10Hz repetition rate. I have already inserted next lines into the text.

*Line 133.* The rotation of the mirror obturator and platforms with phase plates is synchronized with the external trigger of the laser. So laser pulse frequency is about 10 pulse per second, but its exact value is determined by the obturator controller.

23. ln 157-158 Here it would be helpful to already mention Fig. 5. Otherwise, the number of steps seems somehow arbitrary

This is a very interesting offer.

24. Fig. 5a Why do you show this plot?

25. ln 159-164: The same procedure is done for plate B without plate A, isn't it?

*revised text,Line 175.* The rotation angle setting is monitored by the zero position sensors of platforms. When installing the plates in the platform frame, the plate axis can be shifted relative to the sensor at a certain angle, initially unknown. However, a laser pulse must be produced at the moment when the axis of the plates coincides with the reference plane of the lidar. The exact positions of the plates in the frame is set separately for plate A and B. We set one plate (e.g. plate B) in its channel (receiver for plate B) and turn on the rotation. A section of a homogeneous atmosphere with small aerosol content is selected. Figure 5a shows the lidar signals from two photodetectors ($P_{co}$ and $P_{cros}$), summarized over all positions of plate B (red and green lines). A height range from 6 to 9 km was chosen, on which the depolarization ratio (blue line) is constant.

For each pulse, the rotation angle of the plate was recorded and the average value of the depolarization ratio over the range of 6–9 km was calculated. These values are shown in Fig. 5b (bottom frame). The dependence averaged over 30 minutes is shown in the upper frame in Fig. 5b. Minimal depolarization is observed at the 34th step of the platform. The accuracy of platform setting is ± 1 step, which corresponds to 0.03% error with respect to depolarization ratio. Similar adjustment of the plate A gives an exact position at the 45$^{th}$ platform step.

A timing diagram in Fig. 4b shows the position of the laser pulses relative to the zero position of the plates. 31 ms interval (45 steps) for plate A and 23 ms (34 steps) for plate B passes before the first laser pulse. The situation repeats every 8 pulses. As already mentioned, the frequency of laser pulses is strictly synchronized with the rotation of the plates.

29. ln 220 The calibration was made 7 May 2017, the measurements are performed one year later. Did you perform calibration measurements in 2018 as well? What can you say about the stability of such calibration measurements?

Of course, Similar calibration procedures were carried out before measurements in April and June 2018. I will clarify the values of these constants.

32. Why do you study the range -1 to 4_ only? Many lidar systems are operated at an off-zenith angle at 5_. It would be interesting to extend your tilt angle up to 5_, even if the change from 4_ to 5_ will not be significant.

The most interesting is a scanning over 30° when the polarization from oriented plates changes abruptly. But due to the inhomogeneities of ice clouds scanning should be done in a short time. We chose a small scanning angle for this reason. I think in future measurements we will use a wider angle. May be the scanning from -5 to +5 will be used, because the symmetry around vertical position, I suppose, can indicate cloud uniformity. And certainly the scanning around 30° is interesting.

33. ln 250 "Values outside the vertical are close throughout the entire cloud thickness." – Close to what?

Values $\delta^{Circ}$ outside the vertical are close to 100% throughout the entire cloud thickness.

36. ln 273 How to determine I_0 (for alpha » 4_) if the scanning cycles are only done up to 4_?

Certainly, $I_0$ is obtained by fitting the function by the least squares method. But it is better to remove (a>>4) from the text.

*Revised: Line 315.* $I_0$ is the offset of dependence determined by a signal without the specular component

37. ln 278-279 Can you provide a mean and a standard deviation? Or maybe add it as a dashed line in Fig. 10.

47. Fig. 11 You just show some fitting results without showing the original data points. Can you underlay your fitting curves (in bold) with the data points in the corresponding color (in a light hue). Then, the reader will see the data used for these fits.

I think that the scatter of experimental data for single pulses well demonstrates approximation errors. I added data points to Fig. 11

39. ln 305 "thus, the amplitudes of signals are reduced to one value" – How?

*Line 345.* The relative sensitivity of photodetectors at 532 and 1064 nm was not calibrated. Therefore the intensities of polarization components for 532 nm (both $I_{co}^{Lin}$ and $I_{cros}^{Lin}$) were normalized so that the intensity maximum of $I_{co}^{Lin}$ (0°) in the vertical position coincided with $I_{co}^{Lin}$ (0°) for 1064 nm.

Thank you for your comments. We will take all your remarks into account in preparing the final text.

Sincerely,
Grigory Kokhanenko