**The comments from the authors are written in bold font. All page numbers and line numbers refer to the original draft.**

# Reply to comments by reviewer #1

Limb and nadir viewing satellite observations have become key observational methods for studying the physical processes leading to the formation and driving the variability of polar mesospheric clouds (PMCs). This study is the first to undertake a systematic comparison of limb tomography and nadir observations of PMCs in real common volumes. Both directly observable quantities such as cloud albedo and scattering coefficients are compared as well as inferred cloud properties such as ice mass density and ice water content. Importantly, this is done by thoroughly taking into account the effects of scattering geometry, differences in spatial resolution, as well as - and most importantly - the detailed error budget of the different observations. Given the uniqueness of the two considered data sets as well as the great scientific interest in PMC processes this is an important study that paves the way for future applications of this combined data set for studies into the fundamental properties of PMC. As such I am recommending acceptance of this manuscript provided that the following mostly minor comments are adequately addressed:

**Reply: We thank the reviewer for this encouraging comment and positive feedback to our study. The detailed comments by the reviewer have definitely led to an improvement of the manuscript, and we appreciate the effort put into these comments.**

Abstract:
The statement that ice mass density agrees with ice water content doesn't make sense since these are two totally different quantities (one is the other integrated in the vertical). Of course, when reading the full text it is clear that the authors mean that the two properties are consistent with each other after properly accounting for the vertical extent of the cloud and integrating the limb observations in the vertical. Please clarify

**Reply: Good point. We replaced the text section:**

**"We find that the primary OSIRIS tomography product, cloud scattering coefficient, shows very good agreement with the primary CIPS product, cloud albedo with a correlation coefficient of 0.96. However, OSIRIS systematically reports brighter clouds than CIPS and the bias between the instruments (OSIRIS - CIPS) is 3.4e-6 $sr^{-1}$ (±2.9e-6 $sr^{-1}$) on average. The OSIRIS tomography ice mass density agrees well with the CIPS ice water content, with a correlation coefficient of 0.91. "**

**With the following text section:**

**"We find that the OSIRIS albedo (obtained from the vertical integration of the cloud scattering coefficient) shows very good agreement with the primary CIPS product, cloud albedo with a correlation coefficient of 0.96. However, OSIRIS systematically reports brighter clouds than CIPS and the bias between the instruments (OSIRIS - CIPS) is 3.4e-6 $sr^{-1}$ (±2.9e-6 $sr^{-1}$) on average. The OSIRIS tomography ice water content (obtained from the vertical integration of ice mass density) agrees well with the CIPS ice water content, with a correlation coefficient of 0.91. "**

- Page 1, line 35: Gadsden and Schröder is a nice textbook but certainly not an original scientific reference. Please replace with suitable references of original measurements (e.g., Lübken, 1999 and/or some even older papers from the Stockholm group based on rocket grenade measurements).

**Reply: This has been corrected, the reference Gadsden and Schröder has been replaced by Lübken, 1999.**

- Page 2, line 4: When referring to these initial observations reference should also be made to the paper by Jesse, 1885: Jesse, O., Auffallende Erscheinungen am Abendhimmel, Met. Zeit., 2, 311-312, 1885.

**Reply: The reference (Jesse, 1885) has been added.**

- Page 2, line 8: Please add "e.g.," in front of the reference to the paper by Fritts et al., 1993.

**Reply: This has been added.**

- Page 2, line 9: At the end of the sentence after the reference above, I would add a reference to the classical paper by Witt, 1962: Witt, G., Height, structure and displacements of noctilucent clouds, Tellus XIV , 1 , 1-18, 1962.

**Reply: Reference added.**

- Page 2, line 22: typo "ferquency"

**Reply: Corrected.**

- Page 2, line 26: How can the ALOMAR lidar data allow to make statements on the horizontal extent of clouds?

**Reply: This reference had been misquoted by the authors and we thank the reviewer for pointing this out. The following whole sentence was deleted: "Moreover, their study also contained detailed observations of changes in the horizontal extent of PMCs at different altitudes; specifically, they were able to**

**demonstrate that the altitude of faint clouds decreases during the 22-year period."**

- Page 2, line 39: Delete "systems"?

**Reply: Corrected.**

- Page 3, line 41: Maybe clarify that you are discussing the operational retrievals here.

**Reply: This clarification has been added, and the sentence has been changed to : "Another advantage is that the same assumption regarding the mathematical shape of the particle size distribution, namely a Gaussian distribution, is used in both the OSIRIS and the operational CIPS v4.2 retrieval"**

- General statement to introduction: I am missing a paragraph pointing out what added value the combination of nadir and limb data sets allows to benefit from. The three aims listed on page 4 are all quite technical; in order to make this manuscript fit to the scope of a scientific journal such as ACP, the readers should stress the added value of the combined data set and explain what kind of studies can be better done with the combined data set than with the single data sets alone. A similar statement should also be added to the conclusions/summary and the abstract.

**Reply: We agree, thanks for pointing this out. To address this issue, we updated the text section on p. 3, line 32 - p. 4 line 16 to the following:**

**A comparison of the two instruments is therefore ideally suited for instrument validation and the combination of the two datasets will be valuable in future studies of cloud-wave interaction, studies on particle sizes as well as studies on how the retrieved clouds properties are affected by cloud inhomogeneity. Many scientific questions about the PMC lifecycle are connected to the 2- or 3-dimensional structure of the clouds. Important such questions concern e.g. the effect of gravity waves or dynamical instabilities on the growth, sublimation or appearance of the clouds. Combined observations by (horizontally resolved) nadir instruments and (vertically resolved) limb instruments have a large potential of addressing such multi-dimensional questions. This is true in particular if the datasets involve tomographic analysis, as in the case of the OSIRIS data utilized here.**

**Taking into account that the satellites have different viewing geometry, resolution and sensitivity, we analyze cloud brightness and the cloud ice in the CV and perform a detailed error analysis. One advantage of comparing tomographic OSIRIS observations to CIPS observations is that both instruments measure scattered radiance, although OSIRIS measures with limb-viewing geometry and CIPS uses nadir-viewing geometry. Another advantage is that the**

**same assumption regarding the mathematical shape of the particle size distribution, namely a Gaussian distribution, is used in both the OSIRIS and the operational CIPS v4.2 retrieval.**

**The specific aims of this satellite comparison study are:**

1. **Perform the first thorough error characterization of the Odin OSIRIS tomographic dataset.**
2. **Validate the tomographic retrieval and error characterization by comparing PMC albedo and ice water content from the Odin/OSIRIS retrievals and AIM/CIPS PMC retrievals.**
3. **Establish a consistent method for comparing cloud properties from a limb sounding tomographic data set to a nadir viewing instrument.**
4. **Produce a combined dataset of Albedo and Ice water content that will facilitate future studies of the PMC lifecycle and PMC particle sizes.**

**This study focuses on comparing albedo and ice water content between the instruments. A future goal is to produce a combined dataset that can be used to study for example more fundamental issues such as the assumption of the PMC size distribution, an assumption that has been questioned in the past. Each instrument used alone can only provide either fine horizontal resolution (CIPS) or vertical/coarse horizontal resolution (tomographic OSIRIS). However, when combined in an efficient way, OSIRIS can provide vertical information on cloud structures such as double cloud layers or voids, ice distribution at different altitude levels, and information about the existence of particles of different sizes on different altitude levels that can complement the high horizontal resolution of the clouds from CIPS. Additionally, the combined dataset can be used to investigate how waves (inferred from albedo variations in CIPS) affect the cloud lifetime and how nucleation/sublimation processes affect the vertical distribution of cloud properties (inferred from a vertical cross section from OSIRIS).**

**To Abstract, p.1, line 16, the following text section has been added:**

**Important scientific questions on how PMC lifecycle is affected by changes in humidity and temperature due to atmospheric gravity waves, planetary waves and tides can be addressed by combining PMC observations in multiple dimensions. 2- and 3-dimensional cloud structures simultaneously observed by CIPS and tomographic OSIRIS provide a useful tool for studies of cloud growth and sublimation. Moreover, the combined CIPS/tomographic OSIRIS dataset can be**

**used for studies of even more fundamental character, such as the question of the assumption of the PMC particle size distribution.**

**To p. 23, in beginning of section Discussion and Conclusions, the following sentence was added:**

**The analysis is performed for northern hemisphere 2010 and 2011 for a total set or 180 coinciding orbits at latitudes from 78N to 80N for local times ~ 15.45.**

**To p.23 line 6, the following text section has been added:**

**In this study, we have compared the PMC cloud properties cloud albedo and Ice water content from Odin OSIRIS limb tomography to the nadir viewing AIM CIPS. The analysis is performed for northern hemisphere 2010 and 2011 for a total set or 180 coinciding orbits at latitudes from 78N to 80N for local times ~ 15.45. The OSIRIS tomographic PMC dataset provides combined coarse horizontal and high vertical information, while CIPS provides preeminent horizontal PMC information. When combined in a common volume study, OSIRIS can provide vertical information of structures such as double cloud layers and ice voids as well as detailed particle size and number concentration information at various height levels to the detailed horizontal PMC information from CIPS. This information can be used to study how atmospheric waves of different scales (inferred from albedo variations in CIPS) alters the vertical distribution of cloud properties (inferred from OSIRIS). Additionally to such studies, the combined CIPS/tomographic dataset OSIRIS provide useful insight to more detailed studies of the PMC particle size distribution.**

- Page 6, line 20: This these -> These

**Reply: Corrected**

- Page 7, line 28: Please consider adding a table that summarizes the uncertainties that have been mentioned in the text above. Ideally the corresponding uncertainties from CIPS should also be included to make this discussion easier to follow.

**Reply: Good suggestion. Since we in this paper present the first thorough error characterization for OSIRIS tomography, a table specifying the uncertainties is in place. We added a table on p. 8, specifying OSIRIS uncertainties mentioned in the text. However, since CIPS uncertainties is presented in a very thorough way in Lumpe (2013), we would like to not put CIPS uncertainties in the table, but instead point to this paper for more details.**

- Page 9, line 28: Do you really mean systematic error or just systematic deviation/difference?

**Reply: We mean systematic difference, corrected in text.**

– Figure 2: I am missing a discussion of the shape of this distribution. Is it coincidence that the distribution is roughly symmetric around 50%?

**Reply: We regard the symmetry to be a coincidence. However, we added the following sentence about the shape to p.10 line 12.**
**Fig. 2 shows an apparent dominance of CV that are either almost cloud-free (0%) or cloud-filled (100%). This is related to the choice of the size of the CV. If a larger CV would have been used, the distribution would not show such high numbers of detections for 0 and 100% clouds fraction.**

- Figure 3: Excellent!

**Reply: We appreciate this comment!**

Page 13, line 7: Reference to Baumgarten et al., ACP 2010 should be added.

**Reply: This reference has been added.**

- Page 13, line 17 : Please spell out "IMD".

**Reply: This review comment made us aware of inconsistent use of Ice mass density and the abbreviation IMD, and also of Ice Water Content and the abbreviation IWC throughout the whole manuscript. We decided to introduce the abbreviation IWC in the abstract and Introduction (p.20 line 23) and only use IWC in the rest of the manuscript. The same has been adopted for Ice mass density for consistency. IMD is being first introduced in the abstract and then at p. 3 line 33, and used instead of ice water content in the rest of the manuscript.**

- Figures 4,6, and 7: haven't you regressed these data sets? I recommend to show the regression lines and indicate the corresponding parameters with their error bars.

**Reply: The datasets have been regressed. In the updated manuscript, we show the regression line (in blue) in figure 4, 6 and 7 together with the parameters and error bars.**

- Figure 4: Why is the OSIRIS error bar increasing with OSIRIS albedo?

**Reply: The OSIRIS albedo error in Fig. 4 is a combination of the systematic error caused by calibration and the estimated error due to the vertical integration of scattering coefficient to albedo. For a faint and thin cloud, there is often only a few vertical levels contribute to the error in the vertical integration thus the combined error is small. However for a bright cloud with larger vertical extent a**

***larger number of levels*** **contribute to the error, and therefore the combined error becomes larger.**

- Page 19, line 15/16: clearly three examples from such a large data set cannot be representative. At most they may illustrate the class of comparisons. Please reword.

**Reply: This is true. We changed the sentence on line 15/16: "These orbits were chosen to illustrate both orbits when the instruments show good agreement and when the instruments disagree and are thus representative for the total set of orbits available for this study",**

**to**

**"These particular orbits were chosen to illustrate some examples of when the clouds in the CV show good agreement, and point out some example when the cloud observations in the CV disagree, and thus illustrate for the reader the range of cloud observations available for this study."**

- Page 19, line 22: that are we have -> that we have

**Reply: Corrected.**

**<u>Additional changes to the paper:</u>**

**We noted that CIPS had not been referenced when it was first mentioned in the Introduction, and therefore we added the reference (Russel et al, 2009) on p.2 line 16.**

**We also noted that OSIRIS had not been referenced properly when first mentioned, and therefore changed the sentence on page 3, line 10 : "The OSIRIS PMC retrieval for the normal limb scans assumes that the PMC layer is spatially homogeneous along the instrument line of sight (LOS).**

**to:**

**"The PMC retrieval for the limb-viewing Optical Spectrograph and Infrared Imager System (OSIRIS) (Llewellyn et al., 2004) on the Odin satellite (Murtagh et al., 2002) assumes that the PMC layer is spatially homogeneous along the instrument line of sight (LOS) for the normal limb scans."**