The reply to the anonymous referee #2 (RC2)

We are grateful to the referee for the very attentive reading of our manuscript and for many insightful remarks. We accept part of the criticism, but argue with several comments and general conclusion made by the referee. While preparing the revised version of our article, we took into account all comments made by the referee.

Below, the actual comments of the referee are given in **bold courier font and blue colour**. The text added to the revised version of the manuscript is marked by red colour.

Notice: Since both anonymous referees made several similar remarks, our answers to these remarks which are given in both replies are identical.

Attached are my comments to the manuscript amt-2020-52. After careful reading multiple times it is my opinion that the methodology used in the paper is not adequate to provide a sound interpretation of the data. Because of the complexity of the topic I suggest that the authors rethink the way they have approached the problem, perhaps doing more simulations. I provide more details in the attached comments and offer some suggestions as well, hoping that they can be useful.

The esteemed reviewer makes general conclusion about the inadequacy of the methodology which we used in our study. We can not agree with this conclusion. We used the classical approach to the solution of inverse problem of atmospheric optics: analysis of the forward problem on the basis of simulations, analysis of measurements in several test cases, tuning the retrieval algorithm, processing the experimental data with the help of this algorithm, and the comparison of the results to the independent data. We obtained consistent results. The fact that a number of questions still remain open does not mean that the interpretation had not been sound. Contrariwise, it indicates the complexity of the problem and shows the ways for further research. The referee advises to rethink the way of approaching the problem. We would like to stress that our study is based on experimental multi-year data. Though the experimental setup of the HATPRO radiometer at our measurements site was initially developed for improving temperature retrievals in the lower layers rather than for solving the problem of the LWP gradient detection and so it was not optimal, nevertheless we managed to apply these measurements to the task under consideration and got some promising results. We have already shown in the discussion section that the experimental setup (geometry, sampling, etc.) may have a large impact on the obtained results. Therefore, "rethinking of the approach" may imply also the transfer to a new measurement scenario. This can be done, of course, but we think that it is beyond the scope of the present study. The current study, to our opinion, is complete, non-contradictory and contains new results. To the extent of our knowledge the studies devoted to the detection of horizontal inhomogeneities of atmospheric parameters from ground-based passive microwave measurements are not numerous and ours is the first attempt to solve the specific problem relevant to the LWP gradient in the coastal area. In order to clarify the motivation for our study and the applied methodology, we added the following text at the end of the introduction section:

> To the extent of our knowledge, the studies devoted to the detection of horizontal inhomogeneities of atmospheric parameters from ground-based passive microwave measurements are not numerous and ours is the first attempt to solve the specific problem relevant to the investigation of the LWP gradient in the coastline area. Therefore, we decided that it would be reasonable to present the step-by-step analysis of the problem starting from the consideration of the forward problem and to demonstrate the complexity of the task that faces us. We used the classical approach to the solution of inverse problem of atmospheric optics: analysis of the forward problem on the basis of simulations, analysis of measured quantities for several test cases, tuning the retrieval algorithm, processing the experimental data with the help

of this algorithm, and the comparison of the results to the independent data. Although the concept of using angular measurements to characterize water vapor and liquid water path gradients is feasible, its practical applications are very difficult due to the high variability of the liquid water in the clouds, the inhomogeneity of water vapor, etc.. In addition, we would like to emphasize that the experimental setup of the HATPRO radiometer at our observational site was initially developed for improving temperature retrievals in the lower layers rather than for solving the problem of the LWP gradient detection. However, we managed to apply these measurements to the task under consideration and got promising results.

General comment

The authors have accomplished a large amount of work on a difficult topic such as the interpretation of off-zenith measurements from a microwave radiometer. Although the concept of using angular measurements to characterize water vapor and liquid water path gradients is feasible, its practical applications are very difficult due to the high variability of the liquid water in the clouds, the inhomogeneity of water vapor, the need to know the cloud location, etc.

We completely agree with this remark of the referee. The task that faces us appeared to be much more complicated than expected when the study had been conceived. We revealed that there are many possible directions of further research both in simulating measurements numerically and in conducting the experiment with modified setup.

In spite of the thorough discussion by the authors, it seems that the only certain result so far is that, under certain very controlled conditions such as those in Fig, 6 and 7, the radiometer contains some qualitative information on the presence of a cloud gradient. However, beyond that, most of the following analysis does not yield any conclusive result. The discussion in section 5 as well does not really provide a definite reason for the figures after Fig. 7.

First of all, we dare to suspect that the referee meant not Figs. 6 and 7, but some others. Figs. 6 and 7 correspond to clear sky conditions everywhere and the cloud gradient can not be expected there. We strongly disagree with the statement made by the esteemed referee that "**most of the following analysis does not yield any conclusive result**". To the best of our knowledge, our results are the first ones which directly refer to the practice of solving the specific problem of LWP gradient detection in the coastline area by ground-based MW method. The outcome of the research is unknown. Also, we would like to stress that our research is based on the experimental data. In this respect any obtained estimations are conclusive since they provide values and data which were unknown before. We can give some examples of the results which we consider conclusive: (a) estimations of the magnitude of the useful signal; (b) the results of T_b measurements in special selected cases; (c) the estimations of the LWP gradient effect and the analysis of error components. However we admit the fact that to some extent it is a philosophical question: what result can be considered conclusive and what result can not…

In addition, the instrument field of view (3 degrees) makes it difficult to interpret the off-zenith measurements if the cloud boundaries are not known. With a 3-degree FOV the radiometer will be sampling a horizontal area of ~ 1 km at 20 km distance when looking up. However, it is not clear if the instrument's field of view was accounted for in the simulations.

We definitely agree that we should have addressed this issue in our manuscript. We did not take the FOV of the radiometer into account. In the revised version we performed extensive simulations of measurements accounting for FOV and demonstrate the validity of our previous results. Please, see below our answer to the remark which concerns extensive simulations.

I understand that what I am suggesting below is hard because of the effort that was put into this manuscript, however I suggest that the authors rethink the entire methodology used for the analysis and, before they look into the data, they conduct extensive simulations of different scenarios. Detailed suggestions are offered at the end of this review.

In the beginning of our reply we have already argued with the referee on the point of "rethinking the entire methodology". We can not understand the criticism expressed by the referee towards our methodology. The esteemed referee does not qualify any our approaches and results as "erroneous". We have the feeling that the referee expects that minor improvements in setting up the forward and inverse calculations will lead to definite answers which will change the results dramatically. Our opinion is opposite. However, as far as extensive simulations of different scenarios are concerned, we thank the referee for this suggestion, we consider this suggestion as very useful which can improve the estimations made in course of the analysis of the forward problem. We took this suggestion into account in the revised version. We performed extensive modelling of scattered clouds and made corresponding radiative transfer calculations. The new subsection 2.2 was added to the manuscript:

2.2 Modelling of measurements in the atmosphere with scattered clouds

Fig. 5b refers to an overcast atmospheric situation which is the simplest but idealised case for estimation of the magnitude of the LWP gradient effect in the measurement domain. In order to be closer to reality, we simulated the scattered clouds over land and sea in the vicinity of the radiometer using a Monte Carlo method. The observational plane (see Fig. 2) was extended and divided into cells (two rows, each row contained 4 cells of the 12x3.25 km size) located over the Gulf of Finland and two opposite shores. In each cell, the random number generator produced the values of the following cloud parameters: the vertical extent (0.3-2 km, uniform distribution); horizontal size (0.5-5 km, uniform distribution); the cloud placement within a cell (uniform distribution); LWP (lognormal distribution). It should be emphasized that the average horizontal size of generated clouds was much smaller than the size of the water body under investigation. While modelling the LWP values, we considered two situations: one with the existing LWP land-sea gradient and another without such a gradient. The mean LWP values for the first situation were the same as taken previously for overcast conditions: (0.08 and 0.04 kg m^{-2} for land and sea correspondingly). For the second situation, the mean LWP value was taken as 0.08 kg m^{-2} everywhere. The number of generated cases was about 165000. Every instantaneous cloud spatial distribution was combined with one set of the meteoparameter profiles (temperature, pressure, and humidity). For these meteoparameters, the assumption of horizontal homogeneity was used. The sets of profiles were obtained in the course of 2 years of observations by the HATPRO radiometer (2013-2014) with the sampling interval of 2 min. As a result, we obtained a statistical ensemble which characterised all seasons.

The important issue which should be discussed with special attention is the influence of the instrument field-of-view (FOV) on the interpretation of the off-zenith measurements. The 22 and 31 GHz channels are optically transparent even for small elevation angles. If the vertical distributions of atmospheric parameters within FOV at a certain distance from the radiometer can be approximated by linear functions, the effect of FOV will be negligible. The situation can change crucially in case of scattered clouds, especially small size clouds and small elevation angles. With a 3-degree FOV, the HATPRO radiometer will be sampling an air portion of about 1 km vertical size at 20 km distance from the radiometer. Possible configurations of the observational geometry in case of scattered clouds are illustrated in Fig. A. One can see that small clouds may appear entirely within FOV of the radiometer (as shown in Fig. A for the cloud over the opposite shore). Some clouds may be missed by observations due to their location in between the lines-of-sight (LOS) corresponding to different elevation angles. Two or more scattered clouds may fall into FOV. Moreover, one cloud may be detected both in zenith and off-zenith observations.

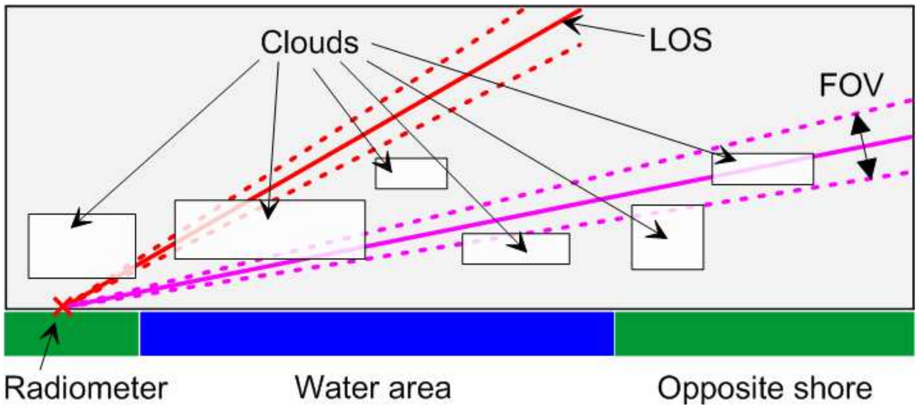

Fig. A: Possible configurations of the observational geometry in case of scattered clouds (a schematic illustration). Solid lines designate the line-of-sight (LOS) of the observations at various elevation angles. Dashed lines show the field-of-view (FOV) of the radiometer.

Fig. A demonstrates the large variety of atmospheric situations. Obviously, for scattered clouds it makes no sense to compare single zenith and off-zenith observations since the LWP gradient signal is a random value under such conditions. It is evident that taking into account not only the spatial variability of clouds but also their temporal variability, we can speak about the LWP gradient component in measurements only in terms of mean values obtained by averaging over large amount of data. Fig. B presents the statistical distributions of simulated brightness temperatures at 31.4 GHz for four elevation angles. For each angle two situations are considered: one with existing LWP land-sea gradient and another without such gradient. The input data for radiative transfer calculations were the Monte Carlo simulations of scattered clouds described above. One can see from Fig. B that for all angles the distribution "with gradient" is shifted towards smaller brightness temperature values if compared to the distribution "without gradient"; however this effect is less pronounced for the elevation angle 11.4° due to the influence of the clouds over the opposite shore of the water body.

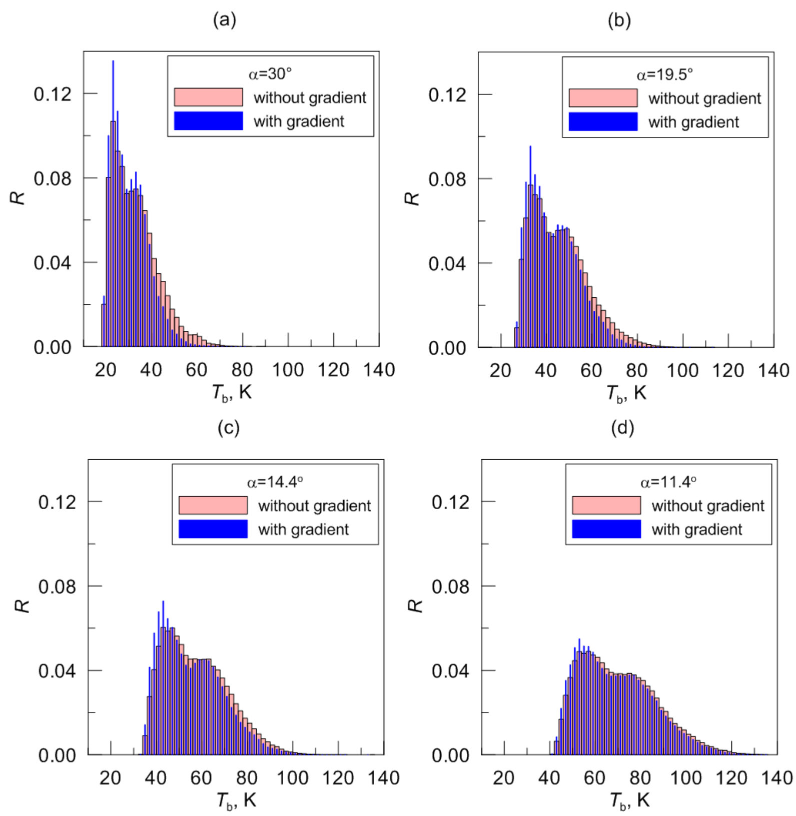

Fig. B: Statistical distributions (in terms of relative frequency of occurrence *R*) of brightness temperatures at 31.4 GHz simulated for four elevation angles and for two situations: one with existing LWP land-sea gradient and another without such gradient. Input data: the Monte Carlo model of scattered clouds.

In order to estimate the component in measured quantity, which is related to the LWP land-sea gradient effect, we analyse the difference between the mean values of T_b datasets which were calculated for situations without and with the gradient. This difference is equivalent to the D_{grad} values shown in Fig. 5b and presents a measure of the "useful signal" relevant to the LWP gradient contribution. Therefore, we use the same designation of this difference and show it in Fig. C as a function of the elevation angle. One can see the dramatic contrast to the overcast case (see Fig. 5b). For scattered clouds, there is no increase of the useful signal for smaller elevation angles. Contrariwise, the D_{grad} values for elevation angles 11.4° and 14.4° are lower than for the angles 19.5° and 30°. The sharp decrease of D_{grad} at 11.4° is explained by the influence of high LWP of the clouds over the opposite shore of the water body.

In order to assess if the instrument FOV affects the magnitude of the useful signal, we present in Fig. C the D_{grad} values which were calculated for infinitely narrow beam width, i.e. neglecting FOV. The results show that there are no considerable differences between the cases "accounting for FOV" and "neglecting FOV". One should keep in mind that we compare the results which were obtained by averaging of a very large number of individual measurements.

However the effect of FOV exists and it is illustrated by Fig. D which shows the statistical distribution of the difference between the brightness temperature obtained neglecting FOV and the brightness temperature obtained accounting for FOV. We suggest that this difference is a measure which characterises in the best way the FOV influence on the results of the interpretation of the off-zenith measurements. The effect of FOV exhibits itself in the form of additional measurements noise which has a systematic and a random component. The absolute value of the systematic component (characterised by the mean value of the distribution) is less than 0.5 K for all four considered elevation angles and this value can be considered as negligible. No specific dependence of the systematic component on the elevation angle can be seen. In contrast, the random component, which is characterised by the standard deviation, increases for smaller elevation angles. The obtained values of the random component can be used for the estimation of a minimal number of individual measurements which should be sampled in order to suppress considerably the influence of FOV. For example, for a set consisting of about 600 individual measurements, the random component of the error due to neglecting FOV at the elevation angle 11.4° will be reduced to the value about 0.1 K. It means that for the current experimental setup averaging over the 10 day time period is enough for suppressing the random error due to FOV.

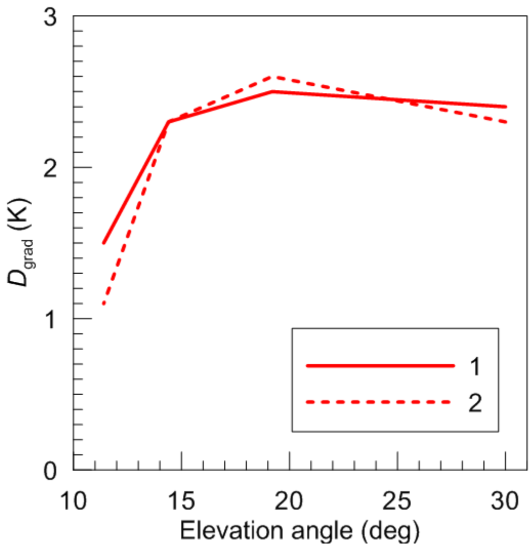

Fig. C: The LWP gradient signal D_{grad} as a function of the elevation angle at 31.4 GHz. Input data: the Monte Carlo model of scattered clouds. Solid line (1) corresponds to the results obtained with account for FOV; dashed line corresponds to the results obtained when FOV is neglected.

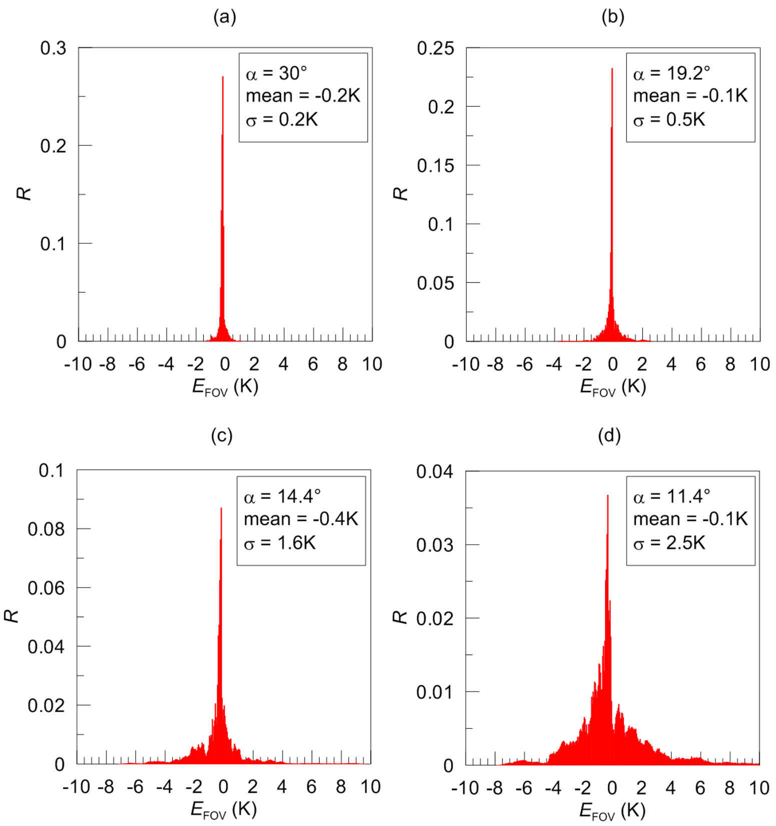

Fig. D: Statistical distributions (in terms of relative frequency of occurrence *R*) of brightness temperature difference E_{FOV} "T_B neglecting FOV minus T_B accounting for FOV" at 31.4 GHz simulated for four elevation angles. Input data: the Monte Carlo model of scattered clouds.

So, the described Monte Carlo simulations of clouds and the brightness temperature calculations lead to several important conclusions. First, we reiterate that for scattered clouds it makes no sense to compare single zenith and off-zenith observations since the LWP gradient signal is a random value under such conditions. Second, for averaged quantities, the magnitude of the component of measured signal determined by the LWP land-sea gradient (useful signal) in case of scattered clouds is rather small and therefore one can expect difficulties in detecting it, especially taking into account the presence of a large number of interfering factors. Third, the instrument FOV affects the results of the off-zenith measurements in case of scattered clouds by introducing additional noise. Its systematic component is small and averaging over several hundred cases can minimise its random component. So the assumption of infinitely small beam width can be used for processing measurements if the analysis is done for averaged quantities.

Specific comments

Line 196: "The difference between measured and calculated brightness temperatures…" However, in eq. 1 the difference is between calculated and measured. Please rephrase.

Corrected.

Lines 209-215: This could be a good reason not to use the retrieved profiles as input back to the radiative transfer code to calculate the brightness temperatures off-zenith. Actually, I think the methodology to use the retrieved profiles to re-derive brightness temperatures should be entirely avoided.

We would like to argue on that point. It is noticed in lines 209-215: "*Here, one important note should be made: the retrieval errors for profiles have random and systematic components (the latter is caused mainly by a priori information used for retrievals). As a result, the term D_{err} might consist of both components also.*" So, it is not necessarily that the impact of the corresponding error will be large if averaged quantities are analysed when the random error component is strongly suppressed.

Fig. 6-11 If I understand this correctly clouds are not simulated in the calculated brightness temperature. If the cloud base and top are not known, then the brightness temperature information off zenith can only give a very qualitative idea on the presence of clouds.

First of all, it is important keep in mind that in these calculations there are no atmospheric parameters which are simulated. We just take the parameters retrieved from zenith observations, assume that they are the same over water body and calculate T_bs for off-zenith geometries. These T_bs are then compared to measured T_bs. Second, all specially selected cases refer to situations with clear sky over the water body. It does not really matter where a cloud is placed vertically when we simulate off-zenith observations. The useful signal is detectable and we show this.

Fig. 6 and 7 and related discussion. It seems to me that, given the difficulty to interpret the signal below 5 degree, and the fact that it could be related to the interaction between the surface and the atmosphere, it is better to limit the scan to angles > 10 degrees altogether.

We completely agree with this advice of the referee. In the study of seasonal features and when making the retrievals we use the limit for the elevation angles 10 degrees.

Line 302: Fig 7: Should it be Fig. 8?

Yes, corrected.

Fig. 11 and related discussion. I am not sure how useful this Figure is as it is hard to conclude anything from it. The behavior of the two quantities is only weakly correlated, if any.

To our opinion, there are similar patterns in temporal behaviour of the compared quantities and these similarities are important. The retrieval results (LWP gradient values) which are presented in the revised version of the article exhibit similarities for the cold season but not for the warm season while the quantities in Fig. 7 demonstrate similar features just during the warm season.

Fig. 12. As stated by the authors the agreement between satellite and radiometer is not improved by passing from the brightness temperature space to the LWP space. The explanations provided in the next section however are hypothetical and it is hard to really understand what is happening.

We agree with this remark of the referee. The approach to training the regression algorithm which we had applied previously appeared to be ineffectual (we trained the algorithm separately for each of the considered seasons and years and considered the overcast case only neglecting scattered clouds with varying horizontal and vertical extent). When preparing the revised version of the manuscript, we made thorough forward modeling of scattered clouds (as suggested by the referee) and on the basis of this modeling we trained the regression algorithm. The proper training yielded new retrieval results which are robust and clearly show the presence of the LWP land-sea gradient and its seasonal features. We added the comparison with the reanalysis data which showed good agreement between the microwave data and reanalysis data. A large part of section 4 has been changed. The new text and figures are presented here:

> In the course of developing the retrieval algorithm, we used two variants of training data sets. At first, we trained the algorithm separately for each of the seasons and years and considered only the overcast case with limited range of variations of the cloud base and the cloud vertical extension. This

approach appeared to be ineffectual and did not produce robust results. It was found that extensive forward modelling of scattered clouds with highly variable parameters was necessary. Therefore, finally, training of the regression algorithms was performed on the basis of the Monte Carlo modelling of the atmosphere with scattered clouds described in subsection 2.2. The complete training dataset included the values of LWP calculated along the line-of-sight and converted to the LWP in the vertical column. In case of crossing several clouds by the line-of-sight the LWPs from all these clouds were taken into account. The brightness temperatures at 22.24 GHz and 31.40 GHz were calculated accounting for the instrument FOV. This training dataset was used to derive the regression coefficients. As a result, for each of the regression algorithms (linear or quadratic) of the LWP retrieval we had at our disposal 8 sets of regression coefficients corresponding to 8 elevation angles. Testing of the regression algorithms in the numerical experiments conducted for simulated overcast conditions and scattered clouds has shown that the algorithms overestimate the true LWP for off-zenith observations with the bias in the range 0.003-0.006 kg m^{-2} (for elevation angle 60°). The bias slightly increases for smaller elevation angles. For zenith observations, the bias is negligibly small. So, we can make the conclusion that the algorithms can not overestimate the LWP gradient, if it is detected while processing field measurements.

…………….

We would like to emphasize that the extensive and thorough comparison of the HATPRO and SEVIRI data on LWP for pixel 243 has already been made and the results have been published (Kostsov et al., 2018b, 2019). Good agreement for daily mean LWP of the ground-based and satellite data has been revealed. Moreover, the cross-comparison of the HATPRO LWP data with the data from two space-borne instruments SEVIRI and AVHRR confirmed the agreement not only for averaged values, but also for single measurements (Kostsov et al., 2019). To date, there were no attempts to compare the satellite and ground-based data on LWP over water surfaces. However, the validity of the satellite data over large water bodies was confirmed implicitly by the comparison of the SEVIRI and AVHRR results over the Gulf of Finland and the Lake Ladoga (Kostsov et al., 2019).

Taking into account the remarks made above, we can analyse Fig. 12. First of all, we pay attention to the fact that after removing the LWP values greater than 0.4 kg m^{-2} from the SEVIRI datasets the D_{LWP} derived from satellite observations became much smaller than shown in Fig. 11 for the complete datasets. However the temporal behaviour remains the same as in Fig. 11 for all seasons if we look at D_{S1}. If we look at D_{S2} and D_{S3} we can notice the increase of values from February to March 2013 instead of decrease as shown in Fig. 11. The most important result shown in Fig. 12 is that the ground-based microwave measurements definitely detect the LWP land-sea gradient during all seasons and this gradient is positive as in case of the satellite measurements (larger LWP values over land and smaller over sea). The gradient is negative only for March 2013 but its corresponding absolute value is small. Comparing the gradients obtained by the ground-based measurements during warm and cold seasons we may conclude that in general the gradients during cold season are smaller than during warm season and not as variable as during warm season. For warm season, the gradient derived from microwave measurements at the 60° elevation angle is smaller than the gradients obtained from measurements at other elevation angles. It is interesting to note that there are no noticeable differences between the values corresponding to elevation angles 11.4°, 14.4° and 19.2° during warm season and between the values corresponding to all considered angles during cold season. This fact leads to the conclusion that the clouds over the opposite shore do not produce a noticeable influence on the results. Therefore hereafter when comparing the SEVIRI and HATPRO data we shall consider only the D_{S1} values.

For the warm seasons of 2013 and 2014, temporal behaviour of the LWP gradient revealed by the satellite measurements completely differs from that obtained by the ground-based measurements. The satellite measurements show two local maxima in June-July and in October while the ground-based measurements demonstrate maxima in May and August-September. The maximal values of the gradient derived from satellite observations are much larger than the maximal values of the gradient derived from ground-based observations. In contrast to the warm season, during the cold season the temporal behaviour of the gradient is the same for the SEVIRI and the HATPRO results. In order to find any explanations for the agreement of the results in terms of temporal behaviour during cold season and the disagreement during warm season, additional investigations are necessary involving thorough assessment of the error budget of the results – not only ground-based but also derived from satellite observations. It should be noticed that the analysis of the quantities in the measurements domain demonstrated several similar patterns in temporal behaviour of D_{TB} and D_{LWP} during warm season of 2014 and cold season of 2013.

It is interesting to compare the obtained values of the LWP land-sea gradient with the data which are provided by reanalysis, namely ERA-Interim from ECMWF (Dee et al., 2011). The main shortcoming of such comparison is the coarse spatial resolution of the reanalysis data. The internal resolution of the ECMWF data is 0.75 deg, i.e. about 80 km which is too poor to describe the scene of our experiment. For higher resolutions of the reanalysis data, the interpolation procedure is applied, but the highest recommended resolution is 0.25 deg (28 km). So we have chosen the 28 km resolution but even in this case we could not apply the reanalysis data to the scene of our experiment. Therefore we selected two areas 0.25×0.25 deg which are the nearest to the HATPRO radiometer and which represent the land surface and the water body. The location of these areas on a map is shown in Fig. E. The ECMWF data for land surface refers to the territory located about 30 km to the south from the HATPRO radiometer. The ECMWF data for the water surface refers to the territory located about 120 km to the west and 30 km to the north from the measurement site. The ECMWF data on LWP for 6 and 12 UTC were collected and averaged over a period of one month.

The comparison of the LWP gradient from SEVIRI, HATPRO and the ECMWF reanalysis is presented in Fig. F. Due to large displacement of the reanalysis data we can not expect the agreement in temporal behaviour but we can compare the average magnitude of the LWP gradient. For a warm season, one can see a very good coincidence of the magnitude of the LWP gradient derived from the ground-based observations and provided by reanalysis. The best agreement can be seen for the period May-July/August. The discrepancies increase during the period August-October 2014. For the cold season in contrast to SEVIRI and HATPRO, the reanalysis provides negative LWP land-sea gradients. However, the absolute values of these gradients are not large. The HATPRO results display positive gradients and the temporal patterns are similar to the patterns shown by the SEVIRI data. In general, we can make three main conclusions from this comparison. First, the SEVIRI and the HATPRO instruments detect positive LWP land-sea gradients during all seasons but the magnitude of the gradient detected by the ground-based instrument is considerably smaller than detected by the satellite instrument. Second, the LWP gradients provided by HATPRO and reanalysis during the warm season are in a very good agreement. Third, the reanalysis data demonstrate negative LWP gradient during cold season in contrast to the SEVIRI and the HATPRO data. The mean values of the LWP land-sea gradient for all considered time periods are given in Table T1. One can see that there are no noticeable seasonal differences in the SEVIRI data while the HATPRO results demonstrate lower values during cold season. The analysis of physical reasons for the seasonal differences in the LWP land-sea gradient is beyond the scope of the present study. To our opinion, such analysis requires much more data including the satellite data sampled over various water bodies.

Also, Fig. F demonstrates how some factors affect the obtained results. We present D_{LWP} obtained by the HATPRO instrument at the elevation angle 14.4° for three scenarios of training the regression algorithm. The main scenario describes scattered clouds, existing LWP land-sea gradient, and the microwave measurements with the account for FOV. The second scenario neglects FOV and the third one describes the conditions without LWP land-sea gradient. One can see both factors produce negligibly small effect on the obtained results. The conclusion was expected since neglecting FOV is equivalent to the presence of additional random noise which is suppressed by averaging. Also, it is important to mention that the presence of the LWP land-sea gradient in the training data set does not automatically provide its detection when processing the field campaign data. The training was performed with respect to LWP values rather than the gradient values. Besides, the training was performed for each elevation angle separately.

Table T1. Mean values of the LWP land-sea gradient (kg m^{-2}) for different time periods derived from the SEVIRI and the HATPRO observations and provided by the ECMW reanalysis.

Season	SEVIRI	HATPRO	ECMWF
2013WH	0.022	0.011	0.009
2014WH	0.025	0.013	0.006
2013CD	0.018	0.003	-0.005
2014CD	0.022	0.005	-0.003

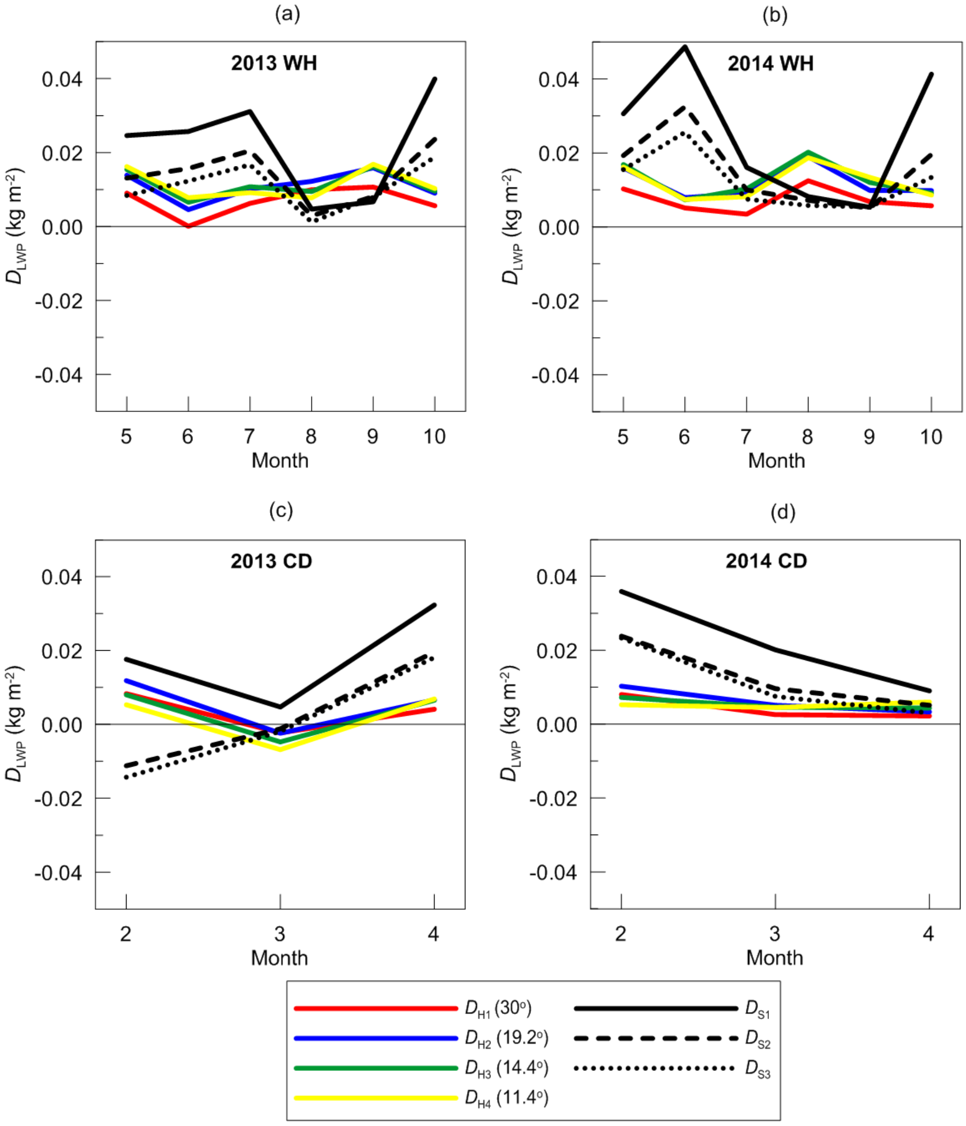

Figure 12: Monthly mean land-sea LWP difference D_{LWP} as a function of time for various time periods obtained from the satellite and the ground-based observations. D_{Hj} (j=1,…,4) denote D_{LWP} obtained by the HATPRO instrument at four elevation angles (colour lines, see the legend). D_{Sj} (j=1,2,3) denote D_{LWP} obtained by the SEVIRI instrument and calculated by three different formulae, see the text.

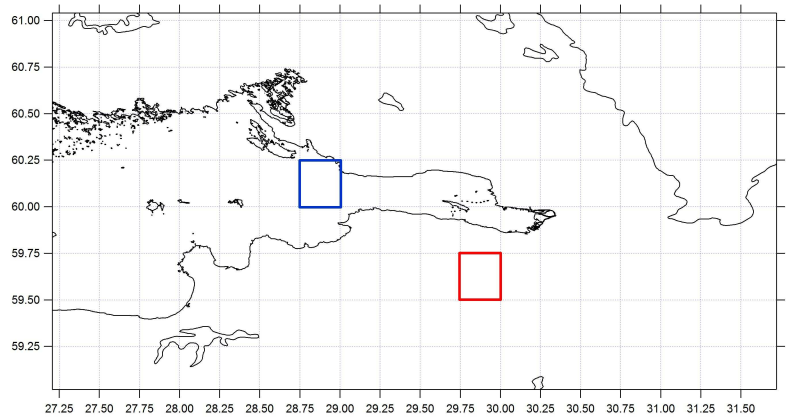

Fig. E: The map showing the geographical location of the reanalysis data on LWP for the land surface (red) and for the water body (blue).

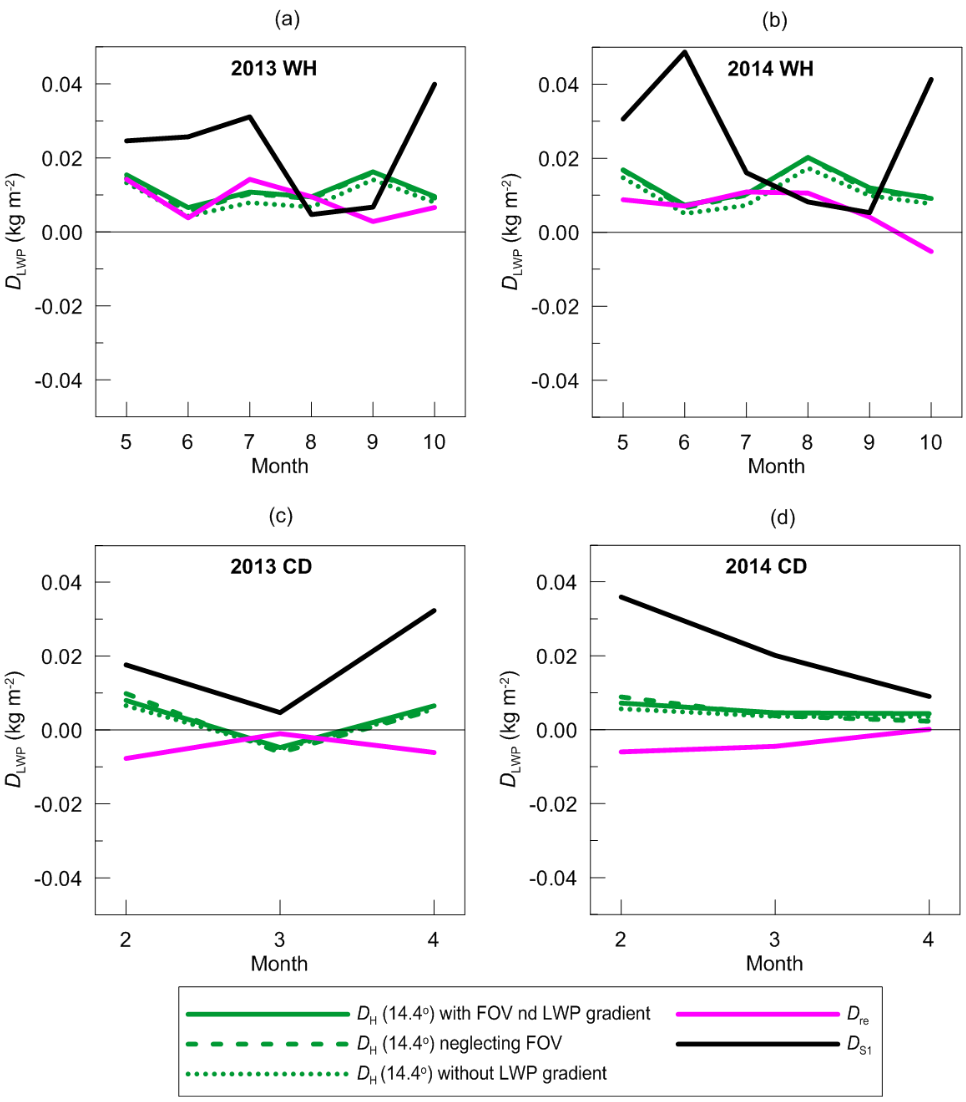

Figure F: Monthly mean land-sea LWP difference D_{LWP} as a function of time for various time periods obtained from the satellite and the ground-based observations. D_H denotes D_{LWP} obtained by the HATPRO instrument at the elevation angle 14.4° for three scenarios of training the regression algorithm (green lines, see the legend). D_{S1} denotes D_{LWP} obtained by the SEVIRI instrument and calculated by formula (6). D_{re} is the LWP land-sea gradient provided by the ECMWF reanalysis.

I wonder if a better approach for this study would be to use the nearby radiosonde database to simulate a large database of scenarios where clouds with different LWP and different cloud base heights and different geometrical thicknesses are simulated at the radiometer's location and at certain distances from the radiometer. The radiometer field of view needs to be simulated as well. This is especially important for off-zenith measurements.

Similar remark has already been made by the referee. We agree with this remark and we are grateful to the referee for the hint to simulate large database. We did it accounting for FOV and simulated scattered clouds (see our answer above). However we used the atmospheric parameters from the HATPRO retrievals rather than from radiosondes. Since the vertical resolution of ground-based microwave remote sensing is poor, we do not see the necessity to use radiosonde profiles.

Brightness temperatures at zenith and different angles for each cloud/distance scenario can then be simulated and a mapping can be established between Tbs differences (zenith – scan) + cloud base height + cloud thickness and PWV, LWP (based on the distance of the simulated cloud) + cloud distance. This could be done with some machine learning given the large

number of variables and scenarios and could provide information on whether it is even possible to separate the signal. It would also give an idea of the uncertainty associated with the analysis. The coefficients could then be used with real measurements. Cloud boundaries for the real cases could be derived from satellite or perhaps reanalysis data.

We are grateful to the referee for this hint. Partly, we have implemented it while preparing the revised version of our manuscript and got new robust results. However we would like to note that implementing of all suggestions of the esteemed referee seems to turn into a separate study (may be not only one study, but several). Our study is pioneering in solving the specific task of the LWP land-sea gradient detection and therefore it is natural that some questions are left open.

Concluding our reply we would like to thank the referee once again for the comments which indeed helped to improve our manuscript. We edited the acknowledgement section accordingly:

> The authors are grateful to two anonymous referees for making very insightful remarks and for introducing several useful ideas which helped greatly to improve the manuscript.

Vladimir Kostsov
on behalf of all co-authors

Note: For convenience, in the revised version of the manuscript the new figures have their own numeration (by letters) and are placed at the end of the manuscript.