P 4.51 ANALYSIS OF UNCERTAINTIES IN SEVIRI CLOUD PROPERTY RETRIEVALS FOR CLIMATE MONITORING

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1. INTRODUCTION

The representation of clouds in climate models is one of the biggest sources of uncertainty in climate studies. To reduce these uncertainties satellites can provide valuable information on cloud properties and their spatial and temporal variation. Satellite observed spectral radiances can be used to retrieve cloud properties because the radiative behaviour of clouds is related to properties such as: thermodynamic phase, optical thickness and droplet effective radius. The accuracy of satellite retrievals is estimated through comparison with ground based observations. This comparison encounters various uncertainties that are not related to retrieval errors, but to the spatial and temporal variability of clouds. In order to assess the accuracy of cloud property retrievals from satellite these uncertainties need to be quantified.

Various methods have been developed to retrieve Cloud Optical Thickness (COT), cloud particle size and Cloud Liquid Water Path (CLWP) from satellite radiances (Nakajima and Nakajima, 1995, Han et al., 1994 and Watts et al., 1998). The principle of these methods is that the reflection of clouds at the non-absorbing visible channel (0.6 or 0.8 μm) is primarily a function of the cloud optical thickness, while the reflection at a water (or ice) absorbing near-infrared channel (1.6 or 3.7 μm) is primarily a function of cloud particle size.

Within the Climate Satellite Application Facility (CM-SAF) of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Royal Netherlands Meteorological Institute (KNMI) (Feijt et al. 2004 and Roebeling et al. 2006) developed an algorithm to retrieve COT and CLWP from visible (0.6μm) and near-infrared (1.6μm) reflectances of the Spinning Enhanced Visible and Infrared Imager (SEVIRI) onboard the Meteosat Second Generation (MSG). The SEVIRI-CLWP retrievals are compared with ground based microwave radiometer LWP (MW-LWP) values to estimate the retrieval accuracy. Although the comparison aims to estimate the accuracy of the SEVIRI-CLWP retrievals, it should be realized that part of the differences observed between ground based and SEVIRI retrievals of LWP result from uncertainties due to:

- Microwave radiometer derived LWP accuracy,
- Co-location of satellite and ground observations,

The co-location error may be split into several independent contributions

- Ground site not coinciding with SEVIRI pixel centre,
- Different Field Of Views (FOV) for ground- and satellite observation,
- Incorrect cloud location for the satellite due to the parallax effect.

Note that the accuracy of MW-LWP retrievals is well known to vary between 20 and 30 g m^{-2} (Dong et al., 2000 and Crewell and Löhnert , 2003). While all other uncertainties show larger variations, and reduce to zero for extended homogeneous clouds. The impact of cloud in-homogeneity is therefore an important consideration for the present study.

This paper aims to quantify the differences in CLWP retrievals due to the uncertainties related to comparing satellite and ground based observations. To estimate the expected differences between ground based and satellite retrieved LWP values one month of SEVIRI-CLWP and MW-LWP retrievals are compared. MODIS AQUA data are used to simulate ground based and SEVIRI LWP fields, which are then compared to quantify the differences due to above described uncertainties. We will discuss how we plan to use these results to develop an improved sampling method for comparing ground based observed and satellite retrieved cloud properties.

The outline of the paper is as follows. The methods used for the uncertainty analysis are presented in section 2. In section 3, the study procedure is described. The results are presented in section 4. Finally, in section 5, the results are summarized and conclusions are drawn.

2. METHODS

In this section we present the methods that are used for the analysis of uncertainties in the comparison between ground based and SEVIRI retrievals of LWP.

The Cloud Physical Properties algorithm (CPP) is based on reflectances at visible (0.6 μm) and near-infrared (1.6 μm) wavelengths. The COT and particle size are retrieved for cloudy pixels in an iterative manner, by simultaneously comparing satellite observed reflectances at visible and near-infrared wavelengths to Look Up Tables (LUTs) of simulated reflectances for given optical thicknesses and particle sizes (Roebeling et al., 2006). The CLWP is computed from the retrieved cloud optical thickness at wavelength and droplet effective radius.

The Doubling Adding KNMI (DAK) radiative transfer model is used to generate LUTs of simulated cloud reflectances. DAK is developed for line-by-line or monochromatic multiple scattering calculations at UV, visible and near infrared wavelengths in a horizontally homogeneous cloudy atmosphere using the doubling-adding method (De Haan et al., 1987; Stammes, 2001).

A schematic representation of uncertainties in the satellite observations that may affect the comparison of SEVIRI and ground based observations is presented in Figure 1. The red box indicates the actual footprint of SEVIRI pixels, which is a diamond shaped area with a nadir resolution of 4.8x4.8 km^2. Since the sampling distance at nadir is 3 km the pixels will appear as 3x3 km^2 squares in the SEVIRI images, as the background image in the Figure shows. The error bars indicate a co-location accuracy of about ± 1 km. The dashed red box illustrates the mismatch between the FOVs of the visible (VIS) and near-infrared (NIR) channels, whereas the green box shows a possible shift of the pixel position due to parallax effects, which are related to cloud height and viewing zenith angle.

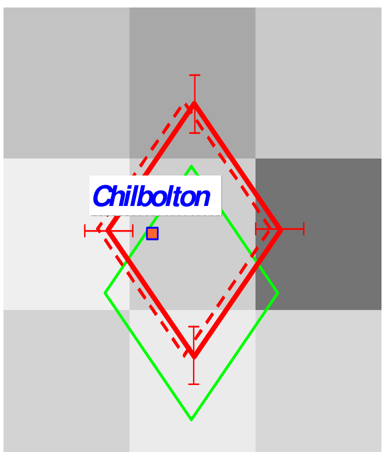

FIG. 1. Schematic representation of the SEVIRI pixel shape, FOV differences between VIS and NIR channels, errors due to co-location differences and the effect of parallax due to cloud top height and viewing zenith angle. The background shows a SEVIRI-CLWP field for 3x3 pixels.

MODIS AQUA limited resolution (1x1 km^2) data are used to analyse the uncertainties between SEVIRI and ground based data. From the original 1x1 km^2 data, new LWP fields were derived at a higher resolution (0.1x0.1 km^2). The algorithm involved conserves the LWP averages over 1x1 km^2, but allows variability in LWP on distances of 0.1 km by extending the power spectra of the original MODIS observation to smaller length scales. The resulting cloud fields are used both to simulate ground based observations, assuming Taylor's hypothesis of frozen turbulence, and to simulate SEVIRI radiances. Figure 2 shows an example of a 15x15 pixels MODIS cloud field that is resamped to a 0.1x0.1 km^2 resolution. The blue box indicates the SEVIRI FOV and the red lines the tracks that would be sampled by the microwave radiometer in case of West and East winds and South and North winds.

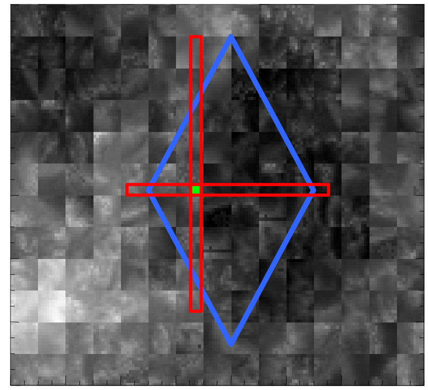

FIG. 2. Same as Figure 1 but then showing example tracks of ground based observations. The background shows a MODIS cloud field resampled to 0.1x0.1 km^2 resolution.

3. STUDY PROCEDURE

In this section we discuss the procedure that is applied to analyse the uncertainties of the SEVIRI-CLWP retrievals.

The radiative transfer calculations are performed at 0.6 and 1.6 μm for water clouds over a dark surface, which have a cloud base at 1000 m and a cloud top height at 2000 m. The clouds are assumed to be plane-parallel and embedded in a multi-layered Rayleigh scattering atmosphere. The atmospheric profiles are taken from the HITRAN database (Kneizys et al. 1996), from which the midlatitude summer is used. The underlying surface is assumed to reflect Lambertian. The formula of Chandrasekhar (1960) is used to calculate the contribution of surface reflectance. For each wavelength cloud reflectances are simulated for optical thicknesses between 0 and 256 and droplet effective radii between 1 and 24 μm. The liquid water cloud particles are assumed to be spherical. The optical properties of the droplets size distribution are parameterized in terms of the effective radius, using a modified gamma distribution with an effective variance of 0.15**.** The scattering phase functions of DAK are calculated with the Mie theory. The retrievals are limited to satellite and solar viewing zenith angle smaller than 60° and relative azimuth angles higher than 100°. This restriction is based on findings of Loeb and Coakley (1998), who expect no systematic bias in cloud property retrievals for these viewing conditions.

First, we present the results of a comparison between ground based MW-LWP and SEVIRI-CLWP values. For this analysis CLWP values were retrieved for one month of SEVIRI data with a 15 minutes temporal resolution. The SEVIRI-CLWP values were compared to 40 minutes mean MW–LWP values that were collected at Chilbolton, UK, as part of the CLOUDNET project.

Second, we evaluate the effect of differences between simulated SEVIRI and ground based CLWP values of about 4000 cloud fields. These cloud fields cover an area of about 15x15 km^2 and were collected from 6 days of MODIS AQUA limited resolution data (1x1 km^2) over an ocean surface. The differences due to cloud in-homogeneities are quantified by comparing 3x6 km^2 and 0.1x0.1 km^2 simulated CLWP values for all cloud field. The 3x6 km^2 data are assumed to represent the resolution of a SEVIRI pixel over Northern Europe.

The differences due to parallax and co-location are estimated by comparing the retrievals of simulated SEVIRI-CLWP with a "correct" position to those with a shifted position. The retrieval differences due to FOV differences are calculated by retrieving CLWP from simulated VIS and NIR reflectance images that were slightly shifted. The uncertainties due to the position of the ground station within the SEVIRI pixel are estimated by comparing the mean CLWP values along the track of ground observations to simulated SEVIRI-CLWP values. The track length is varied between 1 and 15 km to simulate the effect of using different sampling times for the ground based observations.

4. RESULTS

4.1 *Validation of SEVIRI CLWP retrievals*

Figure 3 presents frequency distributions of SEVIRI-CLWP and MW-LWP values for July 2004, Chilbolton, UK. The distributions are prepared for water clouds. SEVIRI cloud thermodynamic phase retrievals were used to detect and exclude ice clouds. Also excluded were observations where rain was reported at the ground station, and MW-LWP retrievals larger than 800 g m^{-2}, which are very unreliable. The resulting data set consisted of 833 observations. The mean MW-LWP and SEVIRI-CLWP values differ less than 2%, with values of 58.5 and 59.6 g m^{-2}, respectively. The Figure shows that SEVIRI observes higher frequencies of clouds with CLWP values between 0 and 25 g m^{-2} than the microwave radiometer. However, the frequencies are similar for clouds with CLWP values higher than 25 g m^{-2}.

Figure 4 presents the differences between MW-LWP and SEVIRI-CLWP retrievals. Here Q66 is the difference between the 17% and 83% quantiles of the deviation between SEVIRI-CLWP and MW-LWP observations. Q95 idem dito mutatis mutandis. For a normal distribution, this would amount to twice the standard deviation. However, the differences

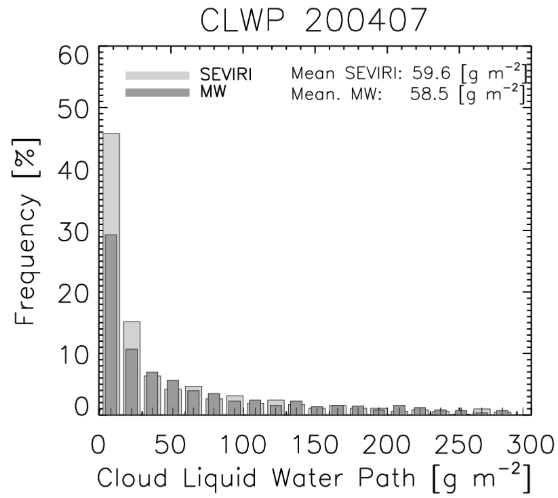

FIG. 3 Frequency distribution of microwave radiometer and SEVIRI-CLWP for Chilbolton during July 2004.

are not normally distributed. This is best observed from the strong peak frequency at differences around zero and the rapid drop of frequencies as the differences increase. The slightly positive skew suggests higher LWP values from microwave radiometer than from SEVIRI. The Q66 value is 60 g m^{-2}, which is about equal to the mean MW-LWP of 58.5 g m^{-2}. The Q95 value of 336 g m^{-2}, which is about six times larger than the Q66 value, indicates that for a limited number of observations the differences between SEVIRI-CLWP and MW-LWP values are very large. Possible reasons for these large Q95 value are the nature of cloud in-homogeneity, multi-layer clouds and the decreasing accuracy of both ground based and SEVIRI LWP retrievals with increasing cloud optical thicknesses.

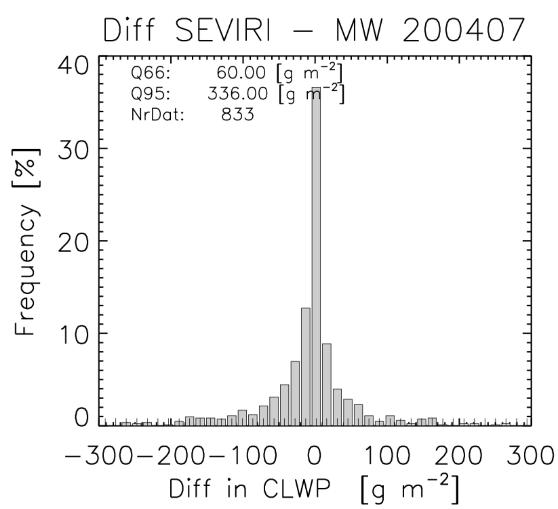

FIG. 4. Frequency distribution of difference between SEVIRI and Microwave radiometer retrieved cloud liquid water path for Chilbolton during July 2004.

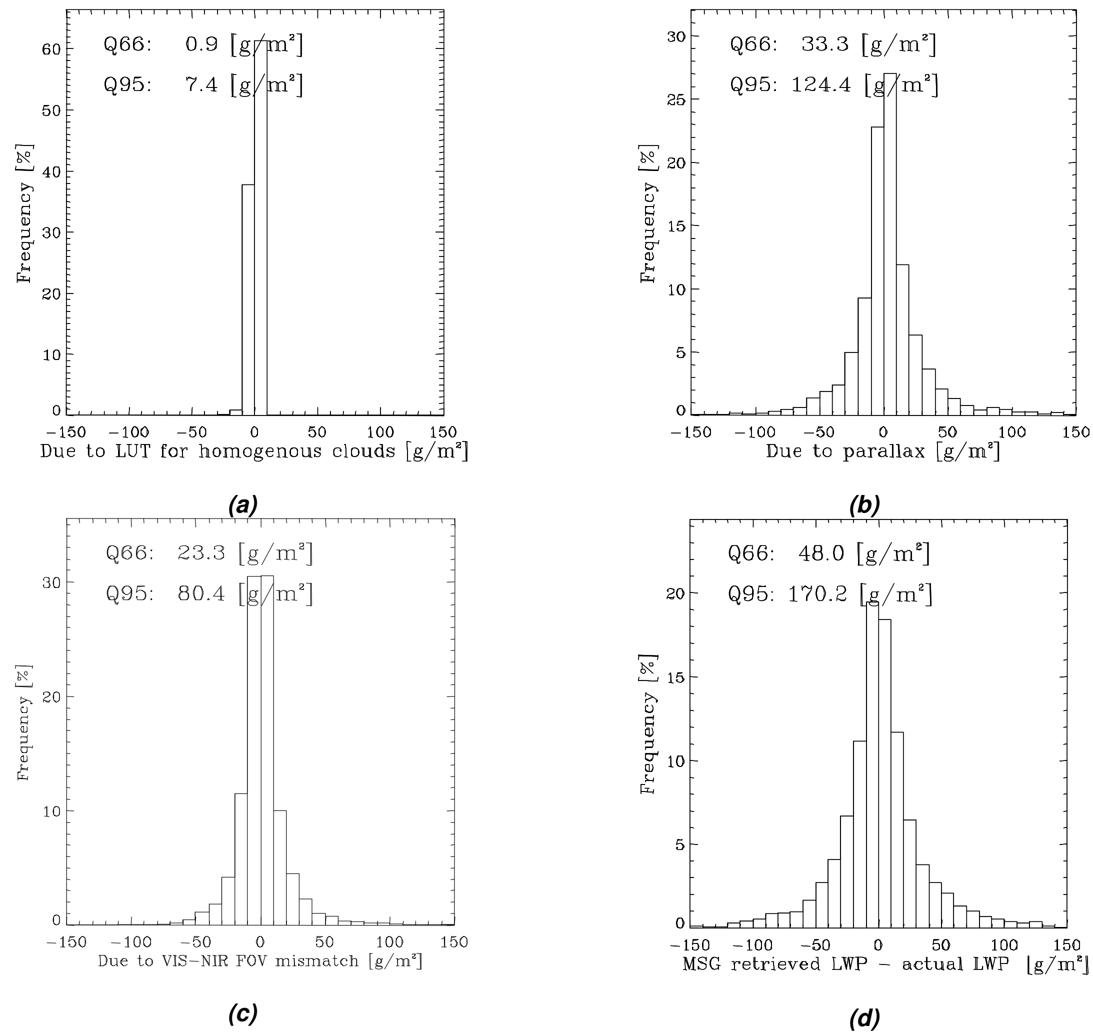

FIG. 5. Examples of differences between simulated satellite and ground based CLWP values due to cloud in-homogeneities (a), parallax (b), VIS–NIR mismatch (c) and the total error due to all uncertainties (d). Where Q66 and Q95 are the 66th and 95th quantile values of the difference between the simulated CLWP values, respectively.

4.2 *Analysis of MODIS data set*

Figure 5 presents the differences between the simulated SEVIRI and ground based CLWP retrievals due to: cloud in-homogeneities, parallax and VIS – NIR mismatch. The lower right panel of the Figure presents total difference off all the uncertainty that are analysed in this paper, for which the Q66 and Q95 values are given in Table 1. Similar to the results of the comparison of SEVIRI-CLWP and MW-LWP values, the differences are not normally distributed. A strong peak frequency occurs at differences of about zero, whereas the frequencies drop rapidly with increasing differences. The graphs do not show a significant skew. The influence of heterogeneities within the SEVIRI pixel has little effect on the simulated SEVIRI-CLWP values. As is well-known, cloud in-homogeneity leads to underestimates of the cloud optical depth. To obtain a solution in the LUTs, effective particle size needs to be overestimated. LWP (the product of optical depth and effective particle size) is affected relatively little by in-homogeneity. From the figures it can be seen that the differences due to parallax and pixel offset have a much larger influence. The largest differences are observed due to parallax. From the graph that presents the total difference of all uncertainties (lower right panel) it can be seen that the total differences add up to Q66 and Q95 values of 48 and 170 g m^{-2}, respectively. With mean CLWP values of about 50 g m^{-2} for the cloud fields this indicates that error can become as large as 100%. The Q66 value of 48 g m^{-2} is close to the Q66 value of 60 g m^{-2} of the comparison of SEVIRI-CLWP and MW-LWP. The Q95 value of

170 g m^{-2} is only half the value of the Q95 value of the SEVIRI-CLWP versus MW-LWP comparison.

TABLE 1. Error budget of LWP retrievals due to known uncertainties between satellite and ground observations.

Effect	***Q66[g m^{-2}]***	***Q95 [g m^{-2}]***
plane parallel assumption	0.9	7.4
VIS – NIR mismatch	23.3	80.4
parallax	33.3	124.4
pixel offset	26.5	95.4
SEVIRI wobble	13.9	69.7
Total	***48.0***	***170.2***

Figure 6 shows the effect of track length on the difference between simulated SEVIRI and ground based CLWP retrievals l. The results are presented for tracks in East-West and North – South wind directions observed at a ground station that co-locates with the centre of the SEVIRI pixel. The overlap with the SEVIRI pixel is about 3.5 km for the East-West track and 7 km for the North-South track. The results for the East-West track (left panel) show that the lowest Q66 and Q95 values correspond to a track length of about 4 km, where the values are 20 and 60 g m^{-2}, respectively. Compared to the East-West track, the minimum values of the North-South tack are almost 50% lower (Q66 = 10 and Q95 35 g m^{-2}) and occur at a longer track length of about 6 km. These results indicate that the optimum track length is closely related to overlap length between the SEVIRI pixel and the ground track, and that a larger overlap length leads to a significant decrease of the minimum Q66 and Q95 values. It can also be seen that the overlap length does hardly affect the Q66 and Q95 values when the track lengths that becoming either shorter or longer than the optimum track length. For example, the Q66 and Q95 values of the 1 or 15 km tracks are similar for the East-West and North-South track.

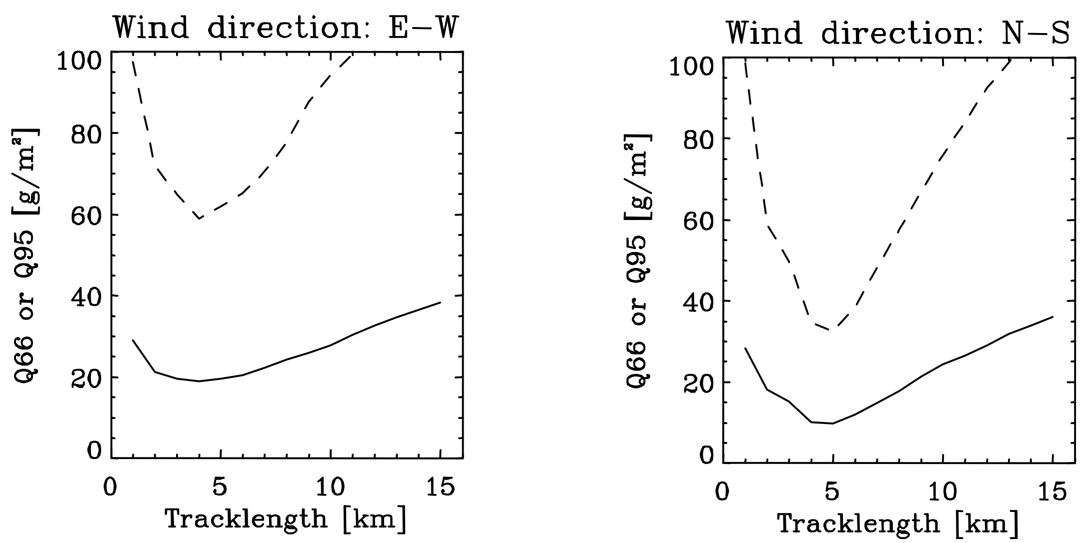

FIG. 6. Differences between simulated SEVIRI and ground based LWP values due to using different track length, given as Q66 (solid line) and Q95 (dashed line) values.

5. DISCUSSION AND CONCLUSION

The present work allows us to estimate the error contributions in a validation study due to the accuracy of microwave radiometer LWP retrievals, cloud inhomogeneities and the overlap between SEVIRI and ground based CLWP retrievals. The comparison between SEVIRI-CLWP and MW-LWP retrievals shows a negligible bias but a severe spread in the observed LWP values. It is shown that the validation causes errors similar or larger than the SEVIRI retrieval process. On the one hand, SEVIRI derived LWP are fairly insensitive to cloud inhomogeneity as explained. On the other hand satellite and ground observations are sampling significantly different portions of the same cloud field.

Based on the results presented in this paper a first estimate of the SEVIRI-CLWP retrieval accuracy can be made. The analysis of MODIS cloud fields showed that the 66th quantile is 48 g m^{-2} for errors due to co-location uncertainties. The accuracy of the MW-LWP retrievals is about 20 g m-^{2}, whereas the error due to observing different portions of the same cloud field is also about 20 g m^{-2}. Because these uncertainties are independent the total error becomes about 55 g m^{-2}, which is very close to the Q66 value of 60 g m^{-2} of the comparison of SEVIRI-CLWP and MW-LWP values. This is a very acceptable result considering the dynamic variation in CLWP values.

Improvements in satellite – ground validation may be obtained by selecting only homogeneous clouds (criteria need to be developed). However, the thus obtained set would not be representative. Unfortunately, this will severly reduce the number of useful observations. Another approach is to consider not a single SEVIRI observation, but a whole field. Many of the discussed errors are related to localization problems and may be alleviated through interpolation of a 2D LWP field. Also, the optimum ground track length corresponds with the track that overlaps best with the SEVIRI pixel. Thus for an optimal correspondence, ground observations need to be averaged over different periods depending on the wind speed at cloud altitude.

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