

TOWARDS A STANDARD PROCEDURE FOR VALIDATION OF SATELLITE DERIVED CLOUD PROPERTIES WITH GROUND-BASED OBSERVATIONS

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ABSTRACT

This paper presents a standard procedure for the validation of cloud properties retrievals from SEVIRI measurements. We use cloud properties datasets from synthetic simulations and ground-based observations to disentangle validation uncertainties from retrieval errors, and suggest a procedure to optimise the validation of satellite retrievals. The evaluation of synthetic Liquid Water Path (LWP) fields shows that the largest validation uncertainties result from differences in the scene that is observed by the satellite and ground-based sensor (e.g. due to parallax shifts), while the uncertainties that are related to the process of retrieving cloud properties from satellite observations are significantly smaller. The differences between synthetic satellite and ground-based LWP values are found to be smallest for ground-based tracks with a length of about 7 km (corresponding to one SEVIRI pixel over Europe). The comparison against real ground-based observations confirms that uncertainties due to the parallax shifts dominate the validation uncertainties of SEVIRI retrievals over Northern Europe (large viewing angles). These uncertainties can be reduced by correcting for parallax shifts and by using Gaussian weighting to optimize spatial interpolation of SEVIRI retrievals and temporal interpolation of ground-based observations. In contradiction with the study of synthetic data, the optimum tracklength of real ground-based observations appears to be much longer, about 4 to 6 SEVIRI pixels.

1. INTRODUCTION

The validation of satellite retrieved cloud properties with ground-based observations is hampered by various sources of uncertainties, among which cloud inhomogeneities, differences in spatial resolution between the sensors and parallax shifts in Field Of View (FOV). Due to these uncertainties the precision of cloud properties retrievals are reduced. Most validation studies use simple sampling strategies to compare satellite retrieved and ground-based observed cloud properties. Roebeling et al. (2008) showed for cloud liquid water path (LWP) retrievals from their cloud physical properties algorithm (Roebeling et al., 2006) that, even when using simple sampling strategies, high agreement was found between instantaneous LWP retrievals from the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) onboard the Meteosat geostationary satellite and time-series of mean LWP retrievals from ground-based microwave radiometer (MWR) measurements.

However, Schutgens and Roebeling (2009) showed that a substantial part of the differences between the two datasets are due to uncertainties in co-location, parallax, position of the ground station and differences due to sampling of different portions of the cloud. Part of these differences may be alleviated through improving the sampling strategy.

The objective of this study is to disentangle validation uncertainties from retrieval errors, and to optimize the procedures to validate satellite retrieved cloud properties. A standard procedure for the validation of cloud properties retrievals from satellite measurements is presented. The validation uncertainties due to cloud inhomogeneities are investigated with a simulated dataset of satellite ($3 \times 3 \text{ km}^2$) and ground-based ($0.1 \times 0.1 \text{ km}^2$) observations for a set of realistic high-resolution Liquid Water Path (LWP) fields that have been generated from MODIS observations. Moreover, real ground-based observations have been used to quantify the validation uncertainties, due to parallax shifts and due to comparing instantaneous satellite retrievals with time-series ground-based observations, for bi-directional reflectance observations and LWP retrievals from the SEVIRI instrument onboard METEOSAT.

The outline of this paper is as follows. In Section 2, the measurements of the Weather Radar and the SEVIRI instrument are described. The methods to retrieve rain rates from Weather Radar and SEVIRI observations are presented in Section 3. In Section 4, the inter-comparison procedure is described. The frequency of precipitation detection and rain rate retrievals from SEVIRI are compared against Weather Radar observations in Section 5. Finally, in Section 6, a summary is given and conclusions are drawn.

2. MEASUREMENTS AND METHODS

a. Simulated cloud properties

The simulated high resolution LWP fields are created from MODIS observations. The high-resolution LWP fields have a spatial resolution of $0.1 \times 0.1 \text{ km}^2$, instead of the resolution of the original observations of $1 \times 1 \text{ km}^2$. The algorithm for creating high resolution LWP fields assumes that clouds are fractal structures. A fractal is defined as a rough or fragmented geometric shape that can be subdivided into parts that are a reduced-sized of the whole. This assumption means that the LWP variance in $1 \times 1 \text{ km}^2$ pixels over 100 km^2 is equal to the LWP variance in $0.1 \times 0.1 \text{ km}^2$ pixels over 1 km^2 . Our algorithm conserves the LWP averages over $1 \times 1 \text{ km}^2$, but allows variability in LWP over a distances of 0.1 km . The power spectra of original MODIS observations are extended to smaller length scales, using information on the variability in $10 \times 10 \text{ km}^2$ fields to prescribe the variability at $0.1 \times 0.1 \text{ km}^2$ (Schutgens and Roebeling, 2009). The simulated LWP fields were prepared from MODIS collection-5 cloud products from the Terra and Aqua platforms. Contiguous cloud scenes were selected for about 600 scenes of $25 \times 25 \text{ km}^2$ over land, and about 1400 scenes of $30 \times 30 \text{ km}^2$ over ocean, for which the above sketched algorithm was applied to prepare the simulated high-resolution LWP fields.

b. Satellite observations

Meteosat Second Generation (MSG) is a European geostationary satellite that is operated by EUMETSAT. The first MSG satellite (METEOSAT-8) was launched successfully in August 2002, and positioned at an altitude of about 36000 km above the equator at 3.4° W . The SEVIRI instrument scans the complete disk of the Earth every 15 minutes, and operates three channels at visible and near infrared wavelengths between 0.6 and $1.6 \mu\text{m}$, eight channels at infrared wavelengths between 3.8 and $14 \mu\text{m}$, and one high-resolution visible channel. The nadir spatial resolution of SEVIRI is $1 \times 1 \text{ km}^2$ for the high-resolution channel and $3 \times 3 \text{ km}^2$ for the other channels.

c. Ground-based observations

The ground-based LWP observations were obtained with MicroWave Radiometers (MWRs) located at Chilbolton (UK, 51.14° N , 1.44° W) and Palaiseau (France, 48.71° N , 2.21° E). Löhnert and Crewell (2003) and Gaussiat et al. (2007) present the method that is used for the conversion of the measured MWR

radiances into *LWP*. Gaussiat et al. (2007) estimate that *LWP* from the MWRs used for the present study has a systematic error and a root-mean-square error of ~ 5 and $\sim 15 \text{ g m}^{-2}$, respectively.

The narrow-band atmospheric flux transmittances used in this study were obtained from two MultiFilter Rotating Shadowband Radiometers (MFRSRs) operated at Cabauw, the Netherlands, and at Heselbach, Germany. The MFRSRs are of type MFR-7 built by Yankee Environmental Systems, Inc., and report irradiances for the total solar spectrum and six narrow spectral bands, with widths of about 10nm.

d. Study procedure

The validation uncertainties due to cloud inhomogeneities are investigated with a simulated dataset of satellite ($3 \times 3 \text{ km}^2$) and ground-based ($0.1 \times 0.1 \text{ km}^2$) observations for a set of realistic high-resolution Liquid Water Path (*LWP*) fields that have been generated from MODIS observations (see Schutgens and Roebeling, 2009). Moreover, real ground-based observations have been used to quantify the validation uncertainties, due to parallax shifts and due to comparing instantaneous satellite retrievals with time-series ground-based observations, for bi-directional reflectance observations (see Deneke and Knap, 2009) and *LWP* retrievals (see Greuell and Roebeling, 2009) from SEVIRI. The validation uncertainties were calculated for different interpolation methods (Gaussian weighting, spatial interpolation, and nearest neighbor interpolation) so as to find the most precise method for interpolating the satellite retrievals near the ground-based site, and the ground-based observations over time.

3. RESULTS

The evaluation of simulated of *LWP* fields shows that the validation errors can be classified in two groups. The errors in the first group are related to the process of retrieving cloud properties from satellite observations, and include the plane parallel bias and the mismatch between different channels. The errors in the second group are related to differences in the scene that is observed by the satellite and ground-based sensor, which include parallax shifts as well as different field-of-views. Calibration errors are not considered in the present study. The *LWP* errors in the second group are significantly larger than those in the first group. The differences between simulated satellite and ground-based *LWP* values are found to be smallest for ground-based tracks with a length of about 7 km (corresponding to one SEVIRI pixel over Europe). Surprisingly, it was found that smaller satellite pixels do not alleviate the problem but rather aggravate it, unless the parallax error is corrected.

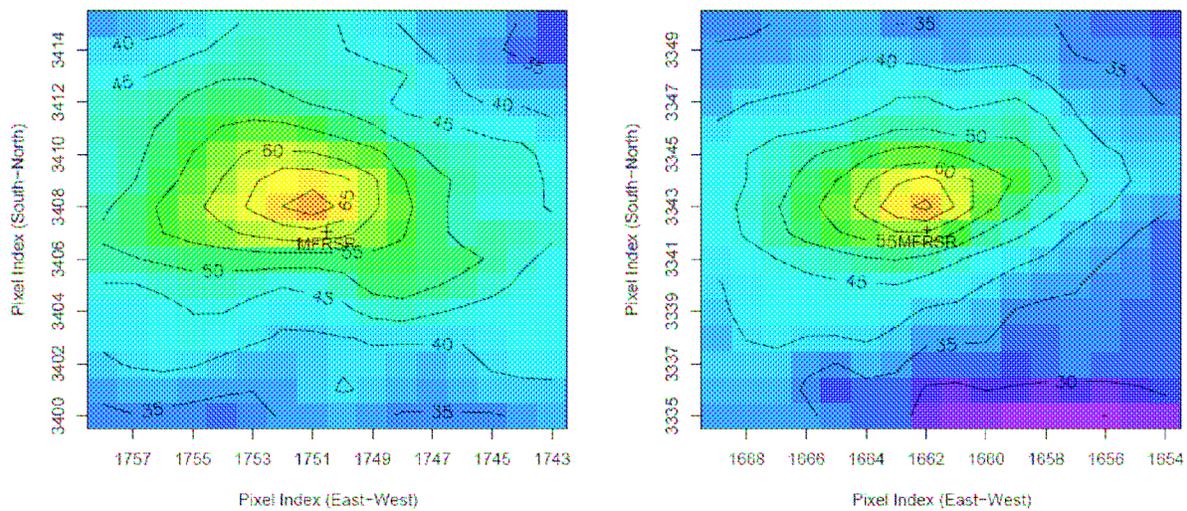


Fig. 1. Contour/intensity map of the explained variance [in %] between the 5 minute resolution time series of flux transmittance and SEVIRI bidirectional reflectance for a 16×16 pixel grid centred around the location of the MFRSRs at Cabauw, The Netherlands (left panel) and Heselbach, Germany (right panel).

The comparison against real ground-based observations confirms that uncertainties due to the parallax shifts dominate the validation uncertainties of SEVIRI retrievals over Northern Europe (large viewing angles). These uncertainties can be reduced by using information on cloud top heights to correct for parallax shifts and by using Gaussian weighting to optimize spatial interpolation of SEVIRI retrievals and temporal interpolation of ground-based observations. Figure 1 shows, for the comparison between SEVIRI observed bidirectional reflectances and multifilter rotating shadowband radiometer (MFRSR) transmittances, that parallax corrections lead to an increase in explained variances from about 0.60 to 0.75. Similar results are found when these parallax corrections procedures are applied for the comparison of SEVIRI and MWR retrievals of LWP.

In contradiction with the study of simulated data, the optimum tracklength of real ground-based observations appears to be much longer, about 4 to 6 satellite pixels. Figure 2 shows that the explained variance and the retrieval precision (expressed by the 68th quantile of the difference between satellite and ground-based LWP values) reach their optimum at sample times (f_t) of about 10, which corresponds to a length of about five satellite pixels. Moreover, both explained variance and precision are highest when both the satellite and ground based LWP values are interpolated with a Gaussian weighing function. These validation results show that longer temporal averaging of the surface measurements is recommended to exclude frequencies with higher variance in ground-based observations. Temporal averaging of the surface measurements over a period of at least 40 minutes is recommended to exclude frequencies that have a higher variance in transmittance than in reflectance.

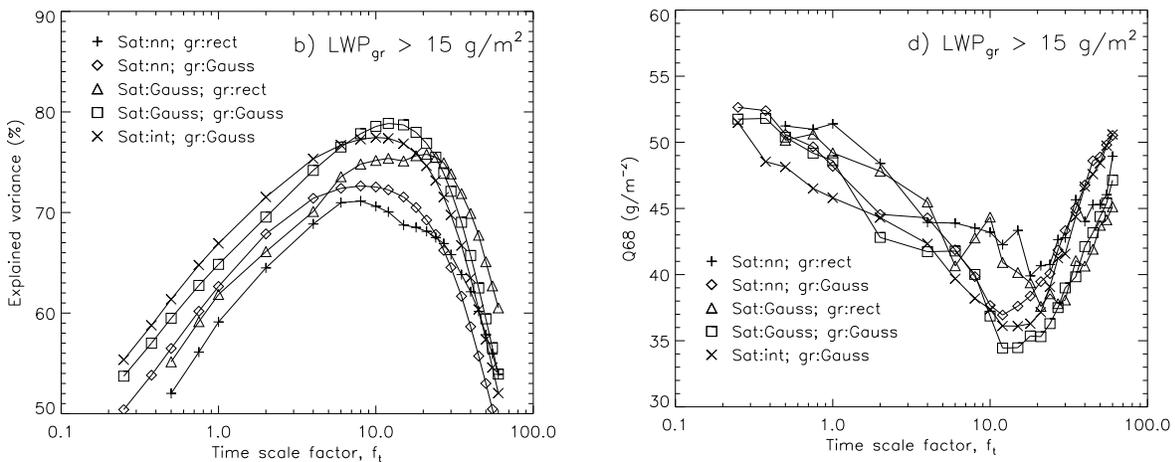


Fig. 2. Explained variance (left panel) and precision (Q68) (right panel) as function of the sampling time (f_t) for different interpolation schemes. The SEVIRI retrievals were interpolated by nearest neighbor interpolation (nn) or by averaging with a Gaussian weight function (Gauss) or by spatial interpolation (int), while the ground-based observations were interpolated by rectangular (rect) or Gaussian (Gauss) weight functions (source Greuell and Roebeling, 2009).

Table 1 presents the maxima of explained variance, as well as the minimum Q68 and Q95 values that are found at the optimum sample times (f_t). The table shows that the optimum values for f_t within the range of 8-21. If rectangular weighting of the ground data is excluded, the range of optimum f_t even narrows down to 8-12, which corresponds to a length of about 4 to 6 satellite pixels. It can be seen that all three evaluation parameters are consistent in assigning the methods of averaging with Gaussian weight functions in both space and time domain as the best method. The combination of the nearest neighbor method to determine LWP_{sat} and rectangular weighting to compute LWP_{gr} is the least successful method, again according to all three statistical parameters. The other combinations lead to intermediate results. The combination of interpolation for the computation of LWP_{sat} and Gaussian averaging in the time domain is according to var_{expl} and Q68 the second best method and according to Q95 the third best method. The difference in the explained variance between the full Gaussian method and the interpolation - Gaussian method is not significant at the 95% level. Differences between the full Gaussian method and the other three combinations are significant at at least the 95% level.

Table 1. Statistical evaluation of the combinations of the various schemes that can be used to compute LWP_{sat} and LWP_{gr} . The table shows maxima of the explained variance, and the minimums of $Q68$ and $Q95$ as a function of f_t . The value of f_t , at which the extremes occur, are given between brackets. The data sets considered includes all samples with $LWP_{gr} > 15 \text{ g/m}^2$. Also, the significance of the improvement of the Gaussian-Gaussian scheme relative to each scheme is given.

Method LWP_{sat}	Method LWP_{gr}	Max. explained variance (%) $LWP_{gr} > 15 \text{ g/m}^2$	Sign. relative to Gauss-Gauss (%)	Min. $Q68$ (g/m^2) $LWP_{gr} > 15 \text{ g/m}^2$	Min. $Q95$ (g/m^2) $LWP_{gr} > 15 \text{ g/m}^2$
near. neigh.	rect. inter.	71.1 (8)	>99.5	39.9 (10)	122.9 (15)
near. neigh.	Gauss	72.6 (8)	> 99.5	36.9 (10)	116.7 (12)
Gauss	rect. Inter.	75.8 (21)	97.5 – 99	37.6 (12)	99.9 (15)
Gauss	Gauss	78.9 (12)	-	34.4 (10)	95.1 (10)
spat. inter.	Gauss	77.5 (10)	< 95	36.1 (12)	102.2 (10)

4. SUMMARY AND CONCLUSIONS

In conclusion, this study has shown that differences between satellite-derived and ground-based cloud properties in validation studies are partly caused by issues associated with the validation itself, in particular scale differences and the parallax. The analysis of a synthetic dataset of cloud properties reveals that significant reductions in validation uncertainties can be achieved by choosing the optimum sampling period for the ground-based observations and by correcting for parallax shifts. An optimum validation strategy is defined and tested for the validation of bi-directional reflectance observations and LWP retrievals from SEVIRI with real ground-based observations. The validation results confirm that the application of the optimum validation strategy leads to a significant decrease of the validation errors and increase of the explained variance. Finally, it was shown that the validation uncertainties can be further reduced when, instead of instantaneous observations, time-series of cloud properties retrievals from SEVIRI are compared against ground-based observations.

5. ACKNOWLEDGEMENTS

This work was part of the EUMETSAT funded Climate Monitoring Satellite Application Facility (CM-SAF) project, and of the SRON funded SYNTHESIS project. Furthermore, we acknowledge the Cloudnet project (European Union contract EVK2-2000-00611) for providing the Instrument Synergy/Target Categorization data, which was produced by the University of Reading using measurements from the Chilbolton Facility for Atmospheric and Radio Research, part of the Rutherford Appleton Laboratory, and from SIRTa, operated by the Institut Pierre Simon Laplace (IPSL).

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