Effect of inhomogeneity on the validation of SEVIRI LWP

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Abstract. We study the impact of cloud variability on the intercomparison of surface- and satellite-based LWP retrievals. In particular we compare LWP retrieved by the geostationary MSG-2 SEVIRI sensor (pixel size: 3 by 6 km^2 at $\sim 50^o$ latitude) to LWP retrieved from observed tracks (0.2 by 2 to 20 km^2) by ground-based MW radiometers. This study is based on both synthetic cloudfields that allow accurate analysis of the various error sources and comparison of real observations from both SEVIRI and ground-based MW radiometers.

Keywords: cloud LWP, satellite retrieval, validation, fractals
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INTRODUCTION

The importance of clouds in the climate system as modifiers of the radiative balance and the hydrological cycle has lead to extensive efforts to observe cloud properties and their variations with time and location. Satellite observations are ideally suited for this, due to their large spatial coverage. However, satellite retrievals incorporate many assumptions (of instruments characteristics and cloud properties) that require that satellite observed cloud properties are properly validated by more detailed and accurate observations made at ground-sites.

Meteosat Second Generation (MSG) is a new series of European geostationary satellites operated by EUMETSAT. Currently METEOSAT-8 (launched 2002) and METEOSAT-9 (launched 2005) observe the complete disk of the Earth through the SEVIRI instrument every 15 min. in 12 different wavelength channels. Sub-satellite spatial resolution of SEVIRI is 3 by 3 km^2 for most channels. The choice of wavelength channels allows for retrievals of surface properties and atmospheric composition (especially clouds [1]).

In this paper, we study the effect of horizontal variability in water clouds on the intercomparison of satellite and ground-based observations. In particular, we study the intercomparison of liquid water path (LWP), which is known to show fractal properties like self-similarity from a variety of studies (satellite observed distributions of radiances and LWP, ground-site observed LWP time-series, in-situ time-series of LWC, see e.g. [2]).

DATA SOURCES

In this section, we will briefly describe the data sources used in the present analysis. For the theoretical analysis of errors, LWP from MODIS collection 5 cloud product from both Terra and Acqua platforms (August 2006 - September 2007, over Northern Europe) will be the main dataset. Within this dataset we searched for contiguous water clouds that showed very reliable (assessment by MODIS team) retrievals of optical depth, water path and effective particle size. All in all 604 contiguous water clouds (25 by 25 km^2) over land were found.

To supplement these cloudfields, cloud top height statistics derived for the CloudNet project from three ground-sites in Northern Europe were used. The same ground-sites also provided MW radiometer data for an intercomparison of actual observations.

MODEL

The contiguous LWP fields found among the MODIS observations were used to derive synthetic high-resolution (0.1 by 0.1 km^2) cloudfields. The procedure is entirely based on the observed self-similar character of LWP distributions. Just like famous fractals like the Sierpinsky sieve or Koch snow flake are built by repeating the same shape at smaller scales, so we propose to repeat LWP distributions observed over 10 km at scales of 1 km (yielding a resolution of 100 m). The original 1 by 1 km^2 MODIS observed LWP fields exhibit power-laws close to $-5/3$ over a small range of length-scales. By filling in each 1 by 1 km^2 MODIS pixel with a scaled distribution of a LWP distribution observed over 10 by 10 km^2, we essentially perform the first step in the creation of a self-similar structure and extend the power-law down to length-scales of 100 m. The real trick is not to use arbitrary LWP distributions over 10 by 10 km^2, but to select appropriate ones based on LWP variability in neighbouring pixels, so that the variation in LWP across pixel boundaries is similar to the variation in LWP within a pixel. Fig. 1 shows both an original MODIS LWP observation, the high-resolution synthetic LWP field derived from it and the power spectrum of the latter.

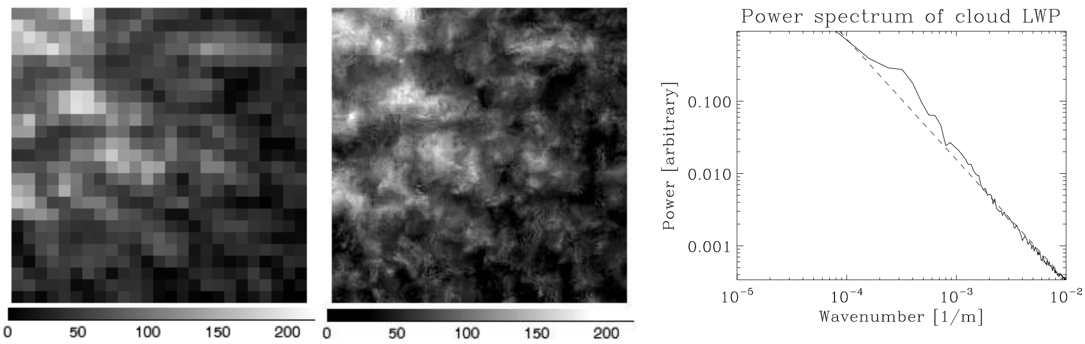

FIGURE 1. The leftmost picture shows an original 25 by 25 km^2 MODIS observed LWP field (gray-scale is g/m^2), the center picture shows th synthetic LWP field derived from it, the rightmost pciture shows the power spectrum of the LWP distribution for the synthetic field (dashed line has $-5/3$ slope).

LWP observations by either satellite or ground-site are simulated by averaging of the synthetic LWP, weighted by the response function of either the SEVIRI sensor, or the MW radiometer. In the case of SEVIRI, the response function is given by the footprint response of the SEVIRI pixel (diamond shape). In the case of the MW radiometer, the response function is a narrow strip simulating the observed track as the cloudfield drifts over the observation site (frozen turbulence assumption [3]).

Various contributions to the difference between satellite and ground-site LWP can be identified. First, an error due to the plane-parallel bias in retrieving the satellite LWP (pure 3D radiative effects will be minimal due to the large size of the SEVIRI pixel). Second, an error because the FOV (field-of-view) of the visual and near infra-red channels for SEVIRI are not identical. Third, an error due to the incorrect attribution of clouds at one altitude to a geo-location at surface level (parallax effect). Fourth, the center of the SEVIRI and radiometer response function do not coincide (offset). Finally, the response functions themselves have substantially different shapes. The usefulness of this separation in different error sources is borne out by the independence of the resulting errors. Fig. 2 schematically shows how we intend to model these error contributions.

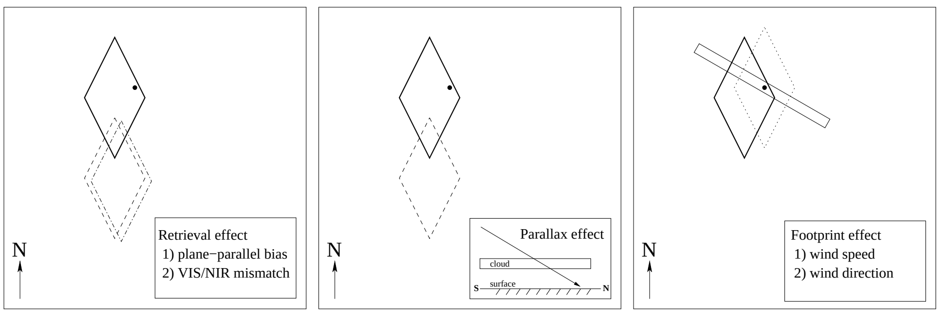

FIGURE 2. The three larger squares represent a 25 by 25 km^2 LWP field as in Fig. 1. The dot represents the location of a ground-site, the solid diamond, the nearest geo-location for a SEVIRI pixel. The dashed pixels represent the observed SEVIRI FOV (left and centre) and the idealized SEVIRI pixel whose centre coincides with the ground site (right).

TABLE 1.

Contribution	ΔQ_{68} **[g/m^2]**					
	Cabauw		Chilbolton		Palaisseau	
	NS	EW	NS	EW	NS	EW
pp-bias	7.8		7.2		7.1	
VIS/NIR	4.1		3.7		3.7	
parallax	32.3		35.3		31.7	
offset	21.6		28.9		17.7	
footprint	15.4	30.3	15.4	30.3	15.4	30.3
total	39.6	47.1	38.9	44.0	45.2	58.0

RESULTS

We can now calculate the difference in LWP due to the previously identified error sources, using our 604 synthetic LWP fields. Results will depend of course, on which ground-site we choose. Here we consider Cabauw, Chilbolton and Palaisseau, see Table 1.

The errors due to different footprints are better analyzed in figures like Fig. 3, showing how they depend on wind-speed and wind-direction. The clear difference between North-South and East-West winds is due to the elongated shape of the SEVIRI pixel (itself due to the steep view angle forsites at $\sim 50^o$ latitude). The difference in wind-speeds (here shown as track-lengths) can be explained likewise.

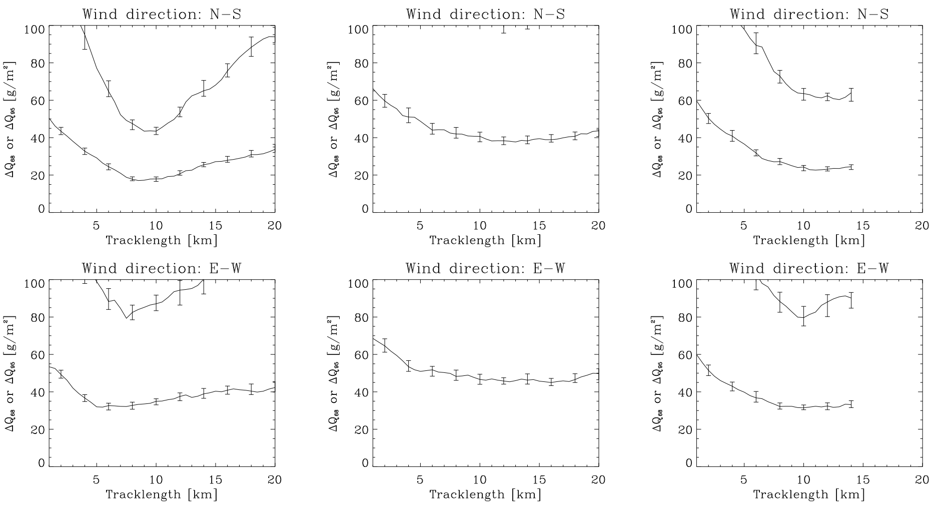

FIGURE 3. LWP differences as a function of track length for either N-S or E-W winds and an ideal SEVIRI pixel whose center coincides with the gound site (left); the SEVIRI pixel nearest to the Chilbolton site (centre); SEVIRI pixel corrected for parallax and site offset (right).

COMPARISON TO REAL OBSERVATIONS

In this section we briefly discuss results obtained from an intercomparison of actual SEVIRI and MW radiometer LWP. In the absence of a well-defined truth, we let the previous analysis guide us. We ask ourselves these questions: 1) can we detect an influence of inhomogeneity on the intercomparison; 2) does correcting the parallax and offset errors improve the intercomparison; 3) are there sampling strategies for the MW radiometer to optimize the intercomparison.

Dividing the observed clouds in two equally large subsets (based on the LWP variation of MW radiometer time-series), it is obvious that the subset with the more inhomogeneous clouds shows larger errors in the intercomparison with satellite data. Allthough median LWP for both subsets is quite similar (50.5 vs 45.1 g/m^2), the errors are significantly larger for the inhomogeneous subset ($\Delta Q_{68} = 49.1$ vs 37.1 g/m^2).

Actually, the above error statistics are obtained after correcting for the parallax and site-offset. Slightly smaller errors (though statistically significant) are found without this correction (e.g. $\Delta Q_{68} = 50.1$ g/m^2 for inhomogeneous clouds).

An optimal validation strategy may be determined by assuming that there are natural spatial and time-scales over which both SEVIRI and MW radiometer should be averaged (or aggregated). Introducing a Gaussian weighting function, Fig. 4 shows the effect of varying both the typical spatial scale (SEVIRI) and typical time scale (MW radiometer) on the explained variance in SEVIRI LWP vs. radiometer LWP. The results are rather surprising: no typical spatial scale is found and the time-scale is quite large at 10 times the SEVIRI pixel size divided by the prevailing windspeed. From our previous analysis, one would expect a spatial scale of the size of a SEVIRI pixel and a timescale close to the travel-time of clouds over that same pixel.

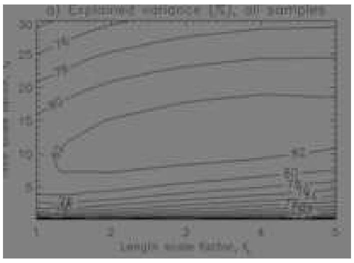

FIGURE 4. Explained variance in LWP when comparing SEVIRI LWP to MW radiometer LWP, as a function of spatial and time scales used to aggragate data

DISCUSSION AND SUMMARY

The purpose of this study is twofold. First, to develop a simple theoretical framework for studying the intercomparison of satellite and ground-based LWP observation (usually done in the context of validating the satellite retrievals). Second, to use this framework to study the contribution of various sources to the overall difference in satellite and ground-based LWP. Overall, our focus here is on the effects of cloud inhomogeneity and sensor FOV.

We have developed a new technique for generating synthetic LWP distributions with a high spatial resolution, based on original MODIS observations with medium resolution. The ensuing error analysis shows that intercomparison likely introduces larger errors than those due to satellite retrieval. However, it was also shown that improved intercomparison is possible if one corrects for certain errors (e.g. parallax effect) and appropriately selects averaging time-intervals for the ground-data. A direct comparison with real SEVIRI and MW radiometer data partly corroborates these findings, partly contradicts them. Further study is needed to see if calibration errors in these sensors maybe responsible.

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