Combining surrogate clouds with geostatistics to ease the comparisons of point radiation measurements with cloud measurements

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ABSTRACT

Geostatistical methods (kriging) aim at estimating the average value. In case of sparse measurements, such fields are too smooth. This can lead to biases in radiative transfer calculations on such a kriged field. Stochastic modelling, e.g. surrogate data, aims at reproducing the structure of data. Surrogate clouds from (profiling) measurements enable us to perform studies on empirical clouds that otherwise may be performed with clouds from numerical models.

Surrogate clouds are well-suited for 3D radiative transfer studies. However, up to now we could only achieve good results for the radiative properties averaged over the field, but not for a radiation measurement located at a certain position. Therefore we have developed and tested a new (so-called conditioned) algorithm that combines the high-quality structure of stochastic (surrogate) modelling with the positioning capabilities of kriging.

Preliminary results on pseudo profiling measurements simulated on LES clouds show that these new surrogate clouds reproduce the structure of the original clouds very well and the minima and maxima are located where the pseudo-measurements sees them. The root mean square error is reduced by a factor three compared to unconditioned surrogate clouds; that means that the number of case studies can be reduced by about a factor nine. The main limitation seems to be the amount of data, which is especially very limited in case of just one zenith-pointing measurement; scanning profiling cloud measurements are clearly very valuable.

1. INTRODUCTION

3D radiative transfer studies require (profiling) cloud measurements at a resolution of around 100 m and covering most of the sky above a radiation measurement site. Taking into account the ever changing character of cloud fields, these requirements can not be met with current instruments. Consequently, one can either use the measurements to drive a dynamical model or use the measured cloud properties to reconstruct a similar cloud field by stochastic modelling. The latter option allows a much more direct use of the cloud measurements and is preferred in empirical studies in which cloud measurements and radiation measurements need to be brought together.

Two statistical properties are essential for radiative transfer (RT) simulations and thus need to be taking into account in stochastic cloud modelling. First of all, the distribution of the cloud water or optical thickness is important for taking into account the nonlinearity of RT. Cloud fields with too little or even no variability (plane-parallel homogeneity assumption) are known to produce too bright cloud tops (Cahalan et al., 1994).

Second, also the structure of the cloud field, in the sense of two-point statistics, e.g. the spatial correlations, is important for RT. Both horizontally uncorrelated fields (Venema et al., 2006a) and fields with a correlation length much larger than the cloud depth (Chambers et al., 1997, Davis et al., 1997) have a higher reflectance than clouds with a correlation length in the order of the cloud depth. Around the scale of the cloud depth, photons can scatter preferentially towards regions with lower extinction, which increases the transparency of clouds. This horizontal photon transport is especially important near cloud edges, i.e. in broken and cumulus clouds.

So-called surrogate cloud fields combine these two statistical properties, the distribution and the spatial correlations, and were shown both theoretically [Venema et al., 2006a] and empirically [Schmidt et al., 2007] to be well suited for studies on cloud structure and radiative transfer.

Traditional algorithms to generate surrogate clouds do not take the position of the measurements into account. For example, if a large cloud was measured in the direction of the sun, the surrogate cloud field would have a large cloud somewhere, but not necessarily in front of the sun (as seen from the measurement site). Consequently, one could only compare field mean optical properties accurately, but comparisons with point measurements on the ground would have been very noise. The new algorithm proposed in this study solves this problem by combining the surrogate data approach with kriging.

Kriging is a geostatistical interpolation method. Based on nearby measurements, the best estimate of the mean value of a certain point is computed taking into account the correlations between this point and the measured points and among the measured points. While kriging is arguably the most accurate interpolation method, it has the disadvantage that it smoothes the field. As an interpolation method, the predicted values (or anomalies in case a background field is used) always have a value that is within the range of the measured ones. As a consequence the distribution of the estimated values is always narrower than the distribution of the measured values. Furthermore, the correlation length of the kriged field will also be longer than the correlation length of the measured values in case of sparse measurements.

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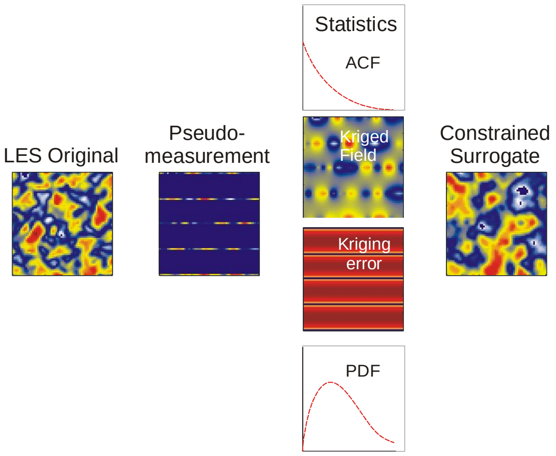

Figure 1. Illustration of the methodology of this study.

Surrogate modelling and kriging have in common that they aim a reconstruction a specific measured field. In this respect they fit well together. In Section 3, the new algorithm to generate surrogate clouds constrained by the kriged field will be explained in more detail. After this the results of the algorithm will be explored in Section 4. First, the methodology of this study and the data will be explained in Section 2.

2. METHODOLOGY AND DATA

2.1 Methodology

The method is made to be applied to real measured examples. However, to be able to evaluate the performance of the algorithms, we work with model clouds from a Large Eddy Simulation (LES). From these clouds pseudo-measurements are computed, which are then used to compute the input needed by the algorithms; see Figure 1. In this way we can compare the radiative and micro-physical properties of the reconstructions with their respective originals in a very accurate way. To compute the radiative properties of the cloud fields, 3D Monte Carlo (MC) radiative transfer computations will be performed for the final study. In the current extended abstract, only the cloud fields themselves are compared.

To simplify this study, all computations will be performed on 2-dimensional Liquid Water Path (LWP) fields instead of on 3-dimensional Liquid Water Content (LWC) fields. The algorithms are able to work in 3D. However, in this way we can ignore instrument specific geometrical problems and concentrate on the algorithms. Furthermore, most kriging algorithms are coded for 2 dimensions and most other applications in the geosciences will also be 2-dimensional.

2.2 LES Cloud fields

The algorithm is validated on two sets of clouds: cumulus (Cu) over land and stratocumulus (Sc) over the ocean; see Figure 2. The 51 cumulus fields represent a diurnal cycle and were generated in the framework of the Atmospheric Radiation Measurement (ARM) project (Brown et al., 2002) and are also employed and described in more detail in Venema et al. (2006a). The fields have a resolution of 100 m in the horizontal and are 66x66 grid boxes in size.

The 29 stratocumulus fields originate from three model runs in which polluted marine stratocumulus clouds are dissolving (Chosson et al., 2007). The cloud field starts relatively homogeneous and slowly dissolves and organises itself in larger patches. The number of grid boxes is 200x200 pixels horizontally with a resolution of 50 m.

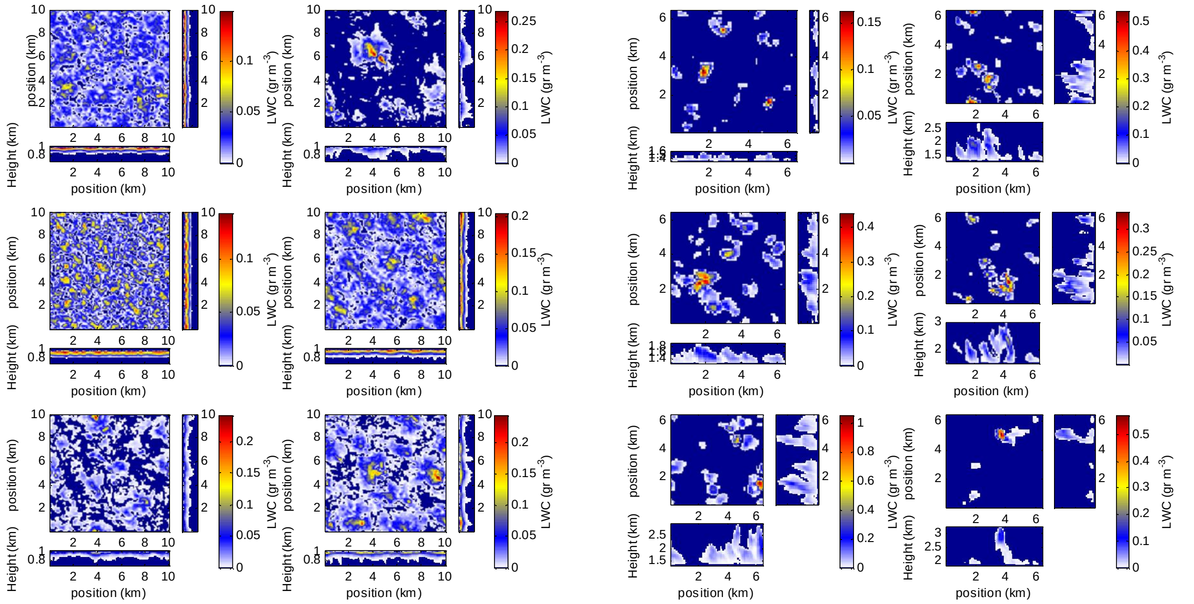

Figure 2. Six example fields of the broken stratocumulus (left) and the sparse cumulus fields (right). The 3D LWC fields are depicted by three panels showing the mean LWC from the top and the two sides.

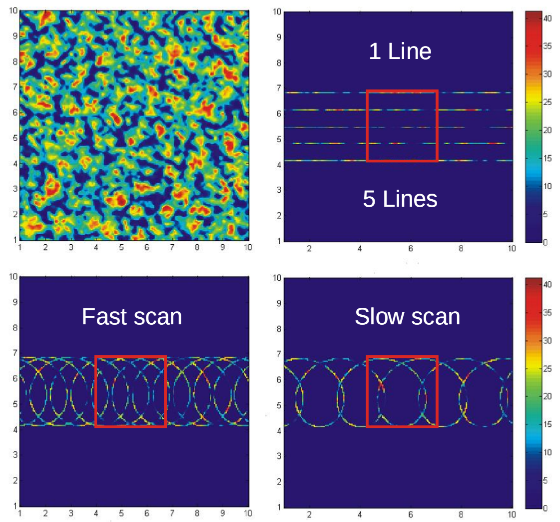

Figure 3. Illustration of the four different sampling strategies that are simulated on the 2D LWP fields.

2.3 Sampling strategies

To generate the pseudo-measurement from the 2D LWP fields, four different sampling strategies were implemented as illustrated in Figure 3. The first set-up represents a zenith pointing microwave radiometer. Using the frozen-turbulence assumption with a cloud drifting by on the wind blowing from east to west, this set-up becomes a line, one time series, of LWP values. First results have showed that the number of samples is a serious problem for this set-up. Therefore, the second set-up again assumes zenith-pointing radiometers, but requires five instruments distributed regularly on a line in north south direction. Thus this pseudo-measurement consists of five lines in east west direction.

The last two set-ups require a scanning microwave radiometer. At a fixed elevation angle of 45° this instrument rotates continuously in the azimuthal plane. Together with the wind, this amounts to a spiral pattern in the 2D LWP field. The first scanning set-up assumes a wind speed of 5 m/s, the second of 10 m/s. The integration time of the instrument is 0.5 s. The clouds are assumed to be at 1.5 km. The diameter of the spiral is thus 3 km large. Therefore, only a square region of 3x3 km in the middle of the fields (the red boxes in Figure 3) will be considered and used for the validation.

3. ALGORITHM

Just as the standard algorithm [Venema et al., 2006a] the new method is iterative and performs an adjustment of the Fourier spectrum (iterative step 1) and of the LWP distribution (step 3); see Figure 4. New is that the algorithm starts with the kriged fields as initialisation instead of white noise. The main change is a second iterative step in which the surrogate field is nudged towards to the kriged field. Initially the nudging is strong, but every iteration the nudging becomes less strong and the surrogate field is allowed to develop its structure; the nudging strength is an exponential function of the number of iterations.

In the nudging both the kriged field and its uncertainty field are used. Where the kriged values are certain (close to the measurements) the nudging is stronger as in more uncertain areas.

The spectral adjustment changes the magnitudes of the Fourier coefficients, which describe the variability as a function of the scale (wavelength), but does not change the phases. The phases determine the position of the Fourier sinuses and keeping them means that the position of the "clouds" is almost not changed and can be set by the new nudging step.

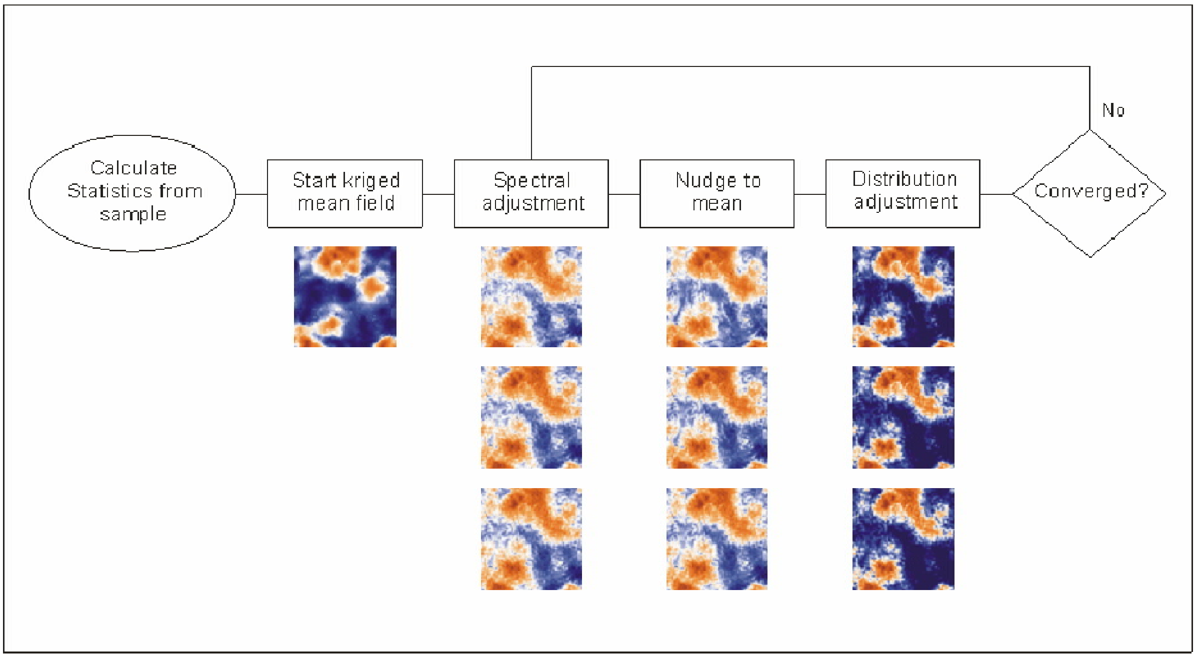

Figure 4. The flow chart of the algorithm that generates surrogate clouds constrained by a kriged field, illustrated with 2D LWP fields from the first three iterative steps.

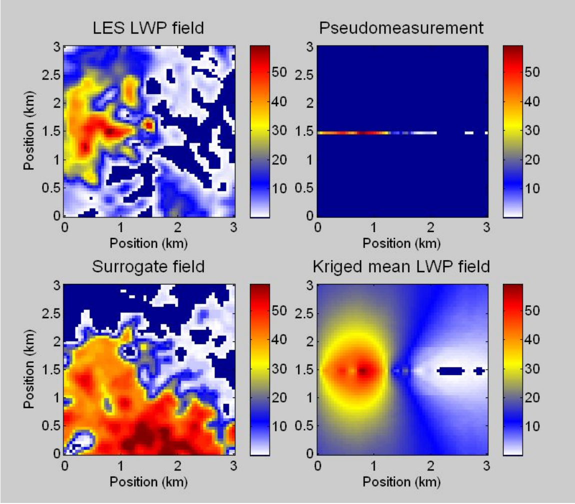

Figure 5. Example of a stratocumulus clouds on which one zenith pointing measurement is simulated and the kriged field and kriging-based surrogate field that is produced by this pseudo-measurement.

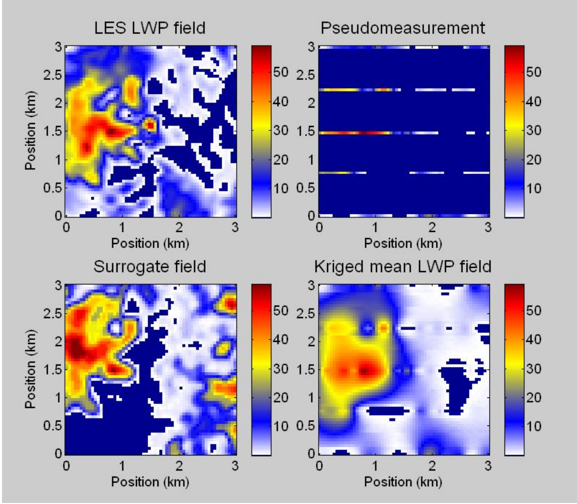

Figure 6. Example of a stratocumulus clouds on which five zenith pointing measurements are simulated and the kriged field and kriging-based surrogate field that is produced by these pseudo-measurements.

4. RESULTS

An example a zenith-pointing pseudo-measurement and its corresponding kriged field and kriging-based surrogate field are shown in Figure 5. Clearly the kriged field (lower right panel) is much smoother, especially far away from the measurement in the middle. The surrogate field (lower left panel) shows much more variability. Compared to the original LES cloud its values are much too high and the size (correlation length) is much too long. However, the pseudo-measurement observes a cloud with high LWP values that is about half the size of the field, which is similar to the surrogate cloud. The problem is thus caused by the sampling problems of a lone zenith-pointing measurement. For our LES stratocumulus clouds, this is one of the cases with the largest sampling problems; for our cumulus clouds such problems can be seen as typical.

Such sampling problems can be solved by making more profiling measurements as illustrated by the example in Figure 6. There one can clearly see that the kriged fields have a problem with the cloud cover, cloud free values being an extreme value that an interpolation method does not produce easily.

Comparing the auto correlation functions of the fields, one can observe that the main structural problem of the kriged fields is its missing variability; the correlation length itself is too long, but not very far off except for the single zenith-pointing measurements.

Comparing the root mean square error of the kriging-based surrogates to normal fully stochastic surrogate fields, one can see that the new algorithm reduces this by about a factor three. Consequently one needs a factor nine less case studies to obtain statistically significant results.

REFERENCES

[1] Cahalan RF, Ridgway W, Wiscombe WJ, Bell TL, Snider JB. 1994. The albedo of fractal stratocumulus clouds. J. Atmos. Sci. 51 : 2434-2455.

[2] Venema V, Meyer S, Gimeno García S, Kniffka A, Simmer C, Crewell S, Löhnert U, Trautmann T, Macke A. 2006a. Surrogate cloud fields generated with the Iterative Amplitude Adapted Fourier Transform algorithm. Tellus 58A : 104-120.

[3] Chambers LH, Wielicki BA, Evans KF. 1997. Accuracy of the independent pixel approximation for satellite estimates of oceanic boundary layer cloud optical depth. J. Geophys. Res. Atmos. 102 : 1779-1794.

[4] Davis A, Marshak A, Cahalan R, Wiscombe W. 1997. The landsat scale break in stratocumulus as a three-dimensional radiative transfer effect: Implications for cloud remote sensing. J. Atmos. Sci. 54 : 241-260.

[5] Brown AR, Cederwall RT, Chlond A, Duynkerke PG, Golaz JC, Khairoutdinov M,. Lewellen DC, Lock AP, MacVean MK, Moeng CH, Neggers RAJ, Siebesma AP, Stevens B. 2002. Large-eddy simulation of the diurnal cycle of shallow cumulus convection over land. Q. J. R. Meteorol. Soc. 128 : 1075-1093.

[6] Chosson F, Brenguier J-L, Schüller L 2007. Entrainment-mixing and radiative Transfer Simulation in Boundary-Layer Clouds. J. Atmos. Res. 64 : 2670-2682.

[7] Schmidt KS, Venema V, Di Giuseppe F, Scheirer R, Wendisch M, Pilewski P. 2007. Reproducing cloud microphysics and irradiance measurements using three 3D cloud generators. Q.J.R. Meteorol. Soc. 133 : 765–780.