Fellowship report for the CLOUDSTATE fellowship 2012

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1. The CLOUDSTATE fellowship

The aim of the CLOUDSTATE fellowship is to determine the strengths and weaknesses of the state-of-art cloud retrieval algorithms from passive imagers (SEVIRI, AVHRR, and MODIS). The retrieval quality of cloud optical, micro- and macro-physical properties is evaluated against independent cloud sensors (CPR, CALIOP, POLDER, MISR, and AMSR-E). Therefore a cloud retrieval data base was created, to which sixteen scientific institutes from Europe and the USA contributed data, among others the EUMETSAT central facilities, the Nowcasting SAF, and the Climate Monitoring SAF. Retrieval datasets of the passive imagers are inter-compared and validated, deviations among them discussed, and uncertainty estimates investigated in order to understand the potentials and limitations of the cloud retrievals with passive imagers. The findings of this fellowship should help to improve our understanding on the optimal use of cloud products in nowcasting, evaluation of numerical weather prediction and climate models and climate monitoring.

The CLOUDSTATE fellowship is strongly connected to the *Cloud Retrieval Evaluation Workshops* (CREWs) that provide an international forum for satellite-based cloud retrieval teams to share their experience with nowadays cloud parameter retrievals based on observations from passive imaging satellites. Initially the collaboration was established at the EUMETSAT funded Cloud Workshops held in Norrköping, Sweden in 2006 and in Locarno, Switzerland in 2009. Meanwhile a 3rd Cloud Workshop took place in Madison/Wisconsin, USA in 2011. The fellow was strongly involved in the organization of this Cloud Workshop. A 4th CREW is planed for March 2014 in Grainau, Germany.

2. Achievements of the first and second year

2.1 Achievements of the first year of the fellowship (2011)

During the first year, the fellow installed the project webpage, implemented the validation software being developed for the first two Cloud Workshops at the KNMI and extended it. The cloud detection of the SEVIRI algorithms was inter-compared and challenging situations for cloud detection were identified. Additionally the fellow was strongly involved in the prepartion and organisation of the 3rd Cloud Retrieval Evaliation Workshop in November 2011. The achievements of the first year of the fellowship are listed in more detail in the following:

Research

A first inter-comparison of the SEVIRI cloud detection retrievals was done. Challenging situations for cloud detection were identified: Thin cirrus, aerosol loaded atmospheres, and broken cloud fields. Comparing the cloud top temperatures, larger deviations among the algorithms were observed in the tropics and for frontal systems. An inter-comparison of the cloud phase (water or ice) revealed that the algorithms retrieve different cloud phase for the cirrus anvils of the inter-tropical convergence zone and for frontal systems. An analysis of the cloud optical depth revealed that for some algorithms the retrieved cloud optical depth of water clouds depend on the satellite viewing angle. A two algorithm analysis (CM SAF and University of Madison/Wisconsin) for the optical depth was completed. The agreement of the cloud optical depth for these two algorithms is better for water clouds than for ice clouds. For more details, have a look at the CLOUDSTATE fellowship report of last year (Hamann, 2011).

The CREW database and Vadiation Software

The CREW database was made available for CREW participants at the FTP server of the University of Lille 1. The CREW dataset contains the cloud property retrieval of 15 research institutes using passive imagers as well as validation datasets from independent sensors. For the 3rd CREW in November 2011 the retrieval datasets were updated.

The fellow installed the inter-comparison and validation software, written by Andi Walther for the first two CREWs, and adapted it to the computational environment of the KNMI. The software was developed further, new functions were added and documentation was extended, e.g. the multi algorithm ensemble average and standard deviation were introduced as analysis tools. A version control system (SVN) was created for the CREW inter-comparison and validation software.

CREW webpage

The fellow created the CREW project website www.icare.univ-lille1.fr/crew in order to increase the visibility of the CREW project. The website describes the intention and goals of the CREW project, the datasets and the participating institutes, and the inter-comparison and validation methods. It also gives an overview over the first three CREW meetings, including the workshop program and the participant lists, provides contact information of the scientific board of CREW, and gives access to reports and documents.

Papers and Reports

The first yearly fellowship report for Eumetsat was submitted (Hamann, 2011).

Contributions to CREW-3

The fellow was strongly involved in the the preparation and organisation of the 3rd CREW in Madison/Wisconsin, USA, including preparation of the program, selection of chairmen and keynote speakers, and communication with the participants. In total 71 scientists attended the 3rd CREW, 35 oral presentations including 6 keynote lectures were given, and 18 posters were presented.

Meetings and Presentations

The results of the first year of the fellowship were presented at the *3rd Cloud Retrieval Evaluation Workhop* in Madison/Wisconsin, USA, and at the *EUMETSAT Conference* in Oslo. As the cloud branch of the ESA Climate Change Initiative pursues similar goals as the CLOUDSTATE fellowship, the fellow participated the *2nd, 3rd, and 4th progress meeting of the cloud project of the ESA Climate Change Initiative*. He gave an overview of the CREW activities and arranged a common 'golden day' for retrieval inter-comparisons. Finally, the fellow presented his progress at the *EUMETSAT Fellow Day* in Darmstadt.

2.2 Achievements of the second year of the fellowship (2012)

In the second year, new algorithms and products were implemented in the database and validation software of CREW. The validation of the cloud top height retrieval products was extended. These investigations will be used for a publication in AMT. The results of the CREW inter-comparison and validation were presented at several conferences. The achievements of the second year of the fellowship are listed in more detail in the following:

Research
A inter-comparison of the SEVIRI cloud top height retrievals started by Andi Walther was extended. A first case study was performed to investigate the performance of the cloud top height retrievals for multi layer, thin cirrus layer, and boundary layer situations. It was found that the approach of the OCA algorithm of retrieving the cloud top height of a possible second layer works well for the investigated case study. A new algorithm for the retrieval of the cloud top height of ice clouds, named COCS, was investigated. It was diagnosed that the cloud top height retrieved by COCS is higher then those of the other algorithms due to the different retrieval approach. Finally a first assessment of the uncertainty estimates of the retrieved cloud product was done. The scientific finding are described in more detail in the next chapter.

The CREW database
The fellow included two new SEVIRI datasets, one by the DLR for ice clouds (COCS) and one from the University of Marburg (EIM) for water clouds into the CREW database. The datasets of the CM SAF (CMS) and from Eumetsat (OCA) were updated. The latter includes products for a possible second cloud layer and uncertainty estimates.

The CREW Vadiation Software
The binary representation of the cloud mask and cloud phase was changed to a floating point representation of cloud cover and ice (or water) coverage. In this way a statistical analysis like multi algorithm average and standard deviation were enabled for these properties. The validation software was extended in order to use the additional groups (COCS and EIM) and additional products (second cloud layer products and retrieval uncertainties of OCA). Filtering functions for the cloud phase and for earth surface types were introduced in that way, that an analysis can easily be performed e.g. for clouds over the ocean or ice clouds only.

Papers and Reports
An article was submitted to the proceedings of the International Radiaion Symposium. The second yearly fellowship report for Eumetsat is submitted with this document. The preparation for a publication of the cloud top height validation in AMT was initialized. The following section of this fellowship report gives an outline for the planed paper.

Meetings and Presentations
In 2012, the scientific results of the second year of the fellowship were presented at the *International Radiation Symposium* in Berlin (Germany), at the *Eumetsat Conference* in Sopot (Poland), and at the *American Geophysical Union Fall meeting* in San Francisco (USA). During the conferences, the results of the CLOUDSTATE fellowships were discussed with the international scientific community. The fellow participated a *CREW progress meeting* that was realized during the Eumetsat Conference. Furthermore the fellow participated a *progress meeting of the ESA Climate Change Initiative cloud project* in Norrkoepping (Sweden). Finally the fellow presented his progress at the *EUMETSAT Fellow Day* in Darmstadt (Germany).

3. Scientific results of the second year

In Section 3.1 the general validation of the cloud top pressure/height products of 11 different retrieval algorithms is presented. In Section 3.2 the newly introduced COCS algorithm from Stephan Kox is described and the first inter-comparison results are presented. Section 3.3 shows the performance of the newly introduced second cloud layer product of the OCA algorithm from Phil Watts. Section 3.4 shows a first assessment of the uncertainty estimates, which is planned to be investigated in more detail at the 4th Cloud Retrieval Evaluation Workshop and thereafter.

3.1 Cloud top height validation

In order to quantify the accuracy of the SEVIRI cloud top height (CTH) retrievals the datasets are validated against independent observations from sensors of the ATRAIN satellite constellation, namely the cloud and aerosol lidar CALIOP (Winker et al., 2009) and cloud profiling radar CPR (Stephens et al., 2002). Both instruments were launched in 2006.

For the validation the AVAC-S validation software was used, that was developed for EUMETSAT and is available to the scientific community (Bennartz, 2010). The CALIOP and CPR data were reprojected on the SEVIRI grid by using the nearest neighboring values. The AVAC-S software can correct for the parralax effect of the SEVIRI viewing zenith angle. The SEVIRI sensor scans the observation disk every 15 min. The scan starts in the south and takes 12 min until it reachs the northernmost point. The CALIOP and CPR data is matched with the SEVIRI observations for which the time shift is smallest, leading to a maximal observation time difference of 7.5 min. In case a SEVIRI algorithm only provides Cloud Top Pressure (CTP) and not the CTH, CTP values were transformed to CTH values using temperature profiles of the ECMWF.

In figure 1 the CTH retrievals of the SEVIRI algorithms are compared with the CALIOP and CPR retrievals. The upper right panel shows the CPR backscatter profile and the CTH retrieved from the CPR data. For cloud free regions the noise level of the radar signal can be observed. Additionally the lower right panel shows the CTH from CALIOP in green and the mean of all SEVIRI algorithms in black.

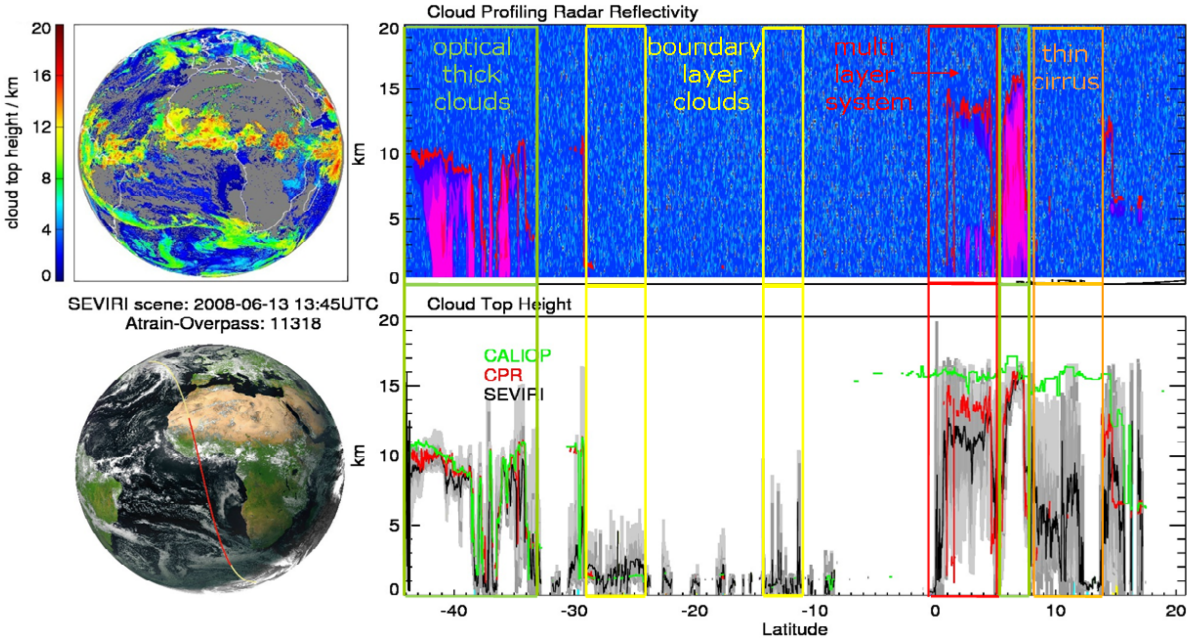


Figure 1: Validation of the Cloud Top Height (CTH) retrievals using SEVIRI with CALIPSO and CPR for 13-06-2008 at 13:45 UTC or ATRAIN overpass 11318. The upper left panel shows the mean CTH of all 11 SEVIRI algorithms. The lower left diagram shows the false color composite of the SEVIRI disk with the path of the ATRAIN satellite constellation in yellow and the part of the track that is shown on the right in red. In the upper right panel the CPR radar reflectivity and the CTH derived from CPR (red) is shown. The lower right diagram shows the CTH derived from CALIOP (green) and CPR (red) observations. The mean of the SEVIRI algorithms is shown in black. Light grey shows the range from minimum to maximum of the SEVIRI retrievals, dark grey indicates the multi algorithm standard deviation. The different cloud regimes are discussed in the text.

In order to understand the differences of the CTHs the sensitivities of the observing systems have to be considered. CALIOP is the most sensitive to cloud particles and is able to detect clouds with a very small optical depth. The radar system CPR is less sensitive than CALIOP. Therefore it is expected, that the CTH of CPR usually is below the CTH of CALIOP. Both systems are active and hence have a high vertical resolution compared to passive sensors. It is 30 m to 60 m for CALIOP and 500 m for CPR. In contrast, the SEVIRI sensor is a passive instrument. The measured radiance originates from different levels, hence the retrieved CTH is a radiatively effective one. Due to the high sensitivity of CALIOP, it is expected that the CTH of passive imager retrievals (SEVIRI) is lower than the CTH of CALIOP and might be similar to the CTH of CPR.

In the following we discuss the different cloud regimes in figure 1. There are two regions marked in green, from 44º S to 34º S and from 5º N to 8º N, where the CPR reflectivity indicates that the clouds in these region are optically thick. The CTHs observed by CALIOP and CPR are similar, indicating that the extinction coefficient is large at the cloud top. The agreement of the SEVIRI retrievals with each other and also with CALIOP and CPR is very good in these regions. CPR and the mean of the SEVIRI retrievals are about 0 to 2 km lower than CALIOP. The standard deviation of the SEVIRI algorithm ensemble is small.

The yellow lines mark regions with boundary layer clouds. The CALIOP observation indicates a mean CTH of 1.3 km. The CPR is most of time not able to detect the boundary layer clouds, probably due to ground clutter. The mean CTH of the SEVIRI algorithm is generally in a good agreement with the CALIOP measurements. First we discuss the differences of the cloud detection by the SEVIRI algorithms and CALIOP. Even though CALIOP is the most sensitive instrument, in some cases clouds are detected by a SEVIRI algorithm and not by CALIOP. A possible reason could be the different fields of view of the instruments. While CALIOP has a footprint of about 70 m, the horizontal subsatellite resolution of SEVIRI is 3 km. Hence it is possible, that SEVIRI sees clouds that are outside the fields of view of CALIOP, in particular for broken cloud fields. The tilted line of sight of the SEVIRI sensor enlarges the SEVIRI pixel size even more and increases the effective COD, too. A second possibility for this kind of devition might be cloud free situations and a false cloud detection of the SEVIRI algorithm. Most often false cloud detections by passive sensors occur during night, when the temperature difference of the cloud and the ground is small, or during day, when the assumptions for the earth surface albedo are not accurate enough. But a false cloud classification during day seems unlikely as bright clouds and dark ocean provide a high contrast. A third possibility is that clouds are not contained in the CALIOP 5 km product like it is reported in Karlsson and Johansson (2013). The 5 km data product of CALIOP processes the measured backscattering ratio where the signal of the cloud detected at higher resultions is substracted. Apart from the differences in the cloud detection, a spread of the retrieved CTHs is observed for the boundary layer clouds, marked as grey shaded area in figure 1. Some algorithms substantially overestimate the CTH of the boundary layer with CTHs as high as 6 km. A similar overestimation of boundary layer CTHs was also reported by Menzel (2008) for the AVHRR sensor. For the conversion of the observed brightness temperature to a cloud top height, assumptions about the temperature profile have to be made. Most often temperature profiles from Numerical Weather Prediction (NWP) models are used for this purpose. Uncertainties of the temperature profiles may originate from an inaccurate analysis/forecast of the boundary layer in the NWP model, from the limited vertical resolution of the NWP model, or from details of the matching procedure of the model dataset with the satellite observations. These temperature profile uncertainties can lead to a substantial displacement of the retrieved cloud top. The conversion of cloud top temperature to heights for boundary layer clouds is especially challenging, as their cloud tops are typically trapped in temperature inversions. It happens that the SEVIRI algorithms detect a lower CTH than CALIOP, too. This might be the case, when there is a temperature inversion and the cloud field is broken. The effective brightness temperature originates from the clouds and the colder surface and is therefore colder as the cloud tops. Hence the algorithm might interpret the colder brightness temperature as cloud top height between surface and clouds. The influence of the temperature profile on the retrieved CTH will be investigated in the third year of the CLOUDSTATE fellowship.

In figure 2, we investigate the individual CTH retrievals the region with multi layer clouds and thin cirrus clouds marked in red and orange respectively. In the red area, there are two different cloud layers according to the CPR reflectivity, see the upper right panel of figure 2. The CALIOP signal indicates that the cloud top of the upper cloud layer is located at 17 km. The CTH retrieved by the

CPR is 1 to 3 km lower than the CTH of CALIOP. This shows that the upper cloud layer has a small extinction coefficient. A second cloud layer is located between 0 and 4 km. Hence, we call this situation a multi layer cloud system. The mean of the SEVIRI results is located in between the two cloud layers at about 12 km. Their standard deviation is as large as 3 to 5 km. In this region, the algorithms of CMS, AWG, and UKM derive a CTH close to the same height as the cloud top of upper CPR cloud layer, whereas FUB and GSF seem to follow the cloud top of the lower cloud layer. The CTH products of OCA algorithm for the second cloud layer (labeled as OCA2) follows nicely the lower cloud layer. This is discussed in more detail in the next paragraph.

In the orange region, CALIOP is able to detect an optically thin cloud layer in around 16 km. The sensitivity of CPR is not sufficient to catch this layer. No other lower cloud layer is indicated by the CPR reflectivity. Therefore, we call this a thin cirrus cloud layer situation. Due to the small cloud optical depth of the cirrus layer, the CTH detected by CALIOP and the radiatively effective CTH retrieved by the SEVIRI algorithms are different. The large spread of SEVIRI CTHs indicates that this is a challenging situation for passive imager retrievals.

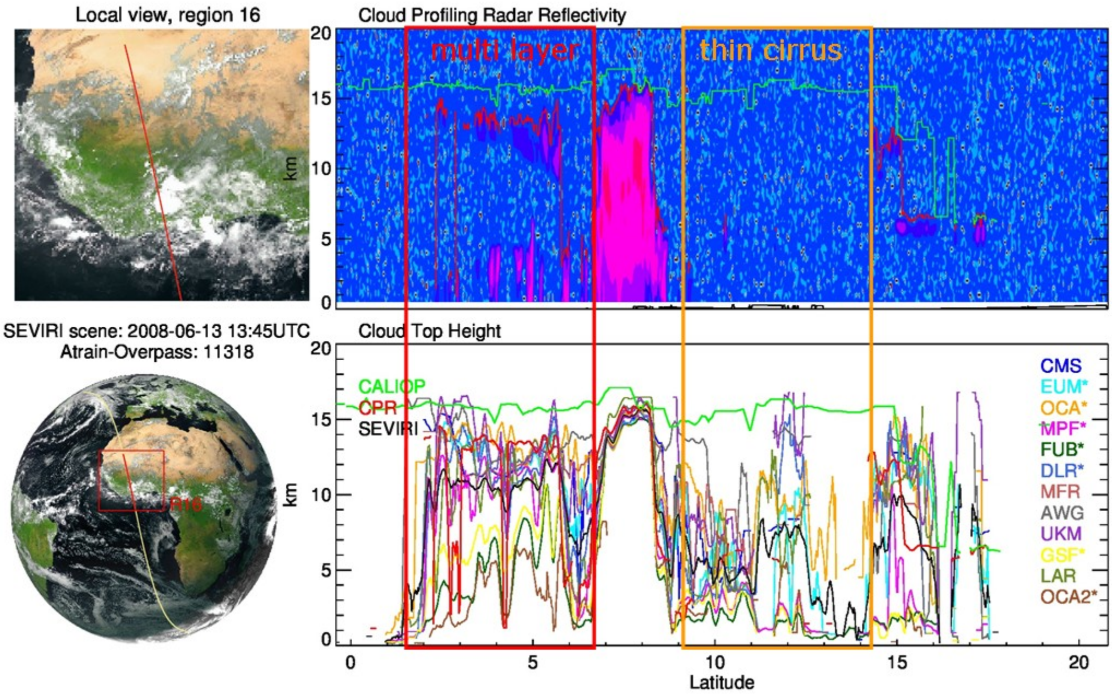


Figure 2: Similar to figure 4, but for a smaller region focussing on a region with multi layer clouds and a thin cirrus clouds. The upper left figure is replaced by a close up of the false color composite. In the lower right figure, not only the mean of the SEVIRI algorithms is shown, but also the results of all individual algorithms (smoothed horizontally by 7 pixels). The groups are CM SAF (CMS), EUMETSAT retrievals (EUM, OCA and MPF), Free University of Berlin (FUB), German Aerospace Center (DLR), Meteo France (MFR), Univeristy of Madison Wisconsin (AWG), UK Metoffice (UKM), NASA Goddard Space Flight Center (GSF), and NASA Langley Research Centre (LAR). OCA2 is a special product of the OCA algorithm, it is the cloud top height of the second cloud layer. Groups that do not submit a cloud top height, but a cloud top pressure (that we converted to cloud top height according to ECMWF data) are marked with a star *.

3.2 Analysis of the newly introduced COCS dataset

In this section, we present the analysis of the new dataset COCS (Cirrus Optical properties derived from CALIOP and SEVIRI during day and night). The COCS algorithm (Kox, 2010, 2011, 2012) retrieves the cloud top height (CTH) and cloud optical depth (COD) of ice clouds from SEVIRI measurements in order to combine the high accuracy of CALIOP and the temporal coverage of SEVIRI. COCS is able to retrieve the COD for non-opaque ice clouds with COD ≤ 3. For larger CODs the CALIOP signal becomes saturated and COCS reports an opaque cloud. The COCS retrieval is verified against CALIOP measurements and validated against airborne HSRL lidar measurements during the WALES and PAZI measurement campaign (Kox, 2011, 2012). The validation shows an excellent performance of the algorithm with a detection efficiency of over 99% and a false alarm rate small than 5% for clouds with COD > 0.1. COCS is able to detect clouds with a smaller optical depth than the cirrus detection algorithm MeCiDA-2 (Krebs, 2007). The fellow added the COCS dataset to the CREW database, as the neural network method might be a new interesting approach for cloud detection and cloud top height retrieval. The comparison with the other SEVIRI retrieval datasets has the potential to reveal strengths and weaknesses of applied retrieval methods.

COCS is a neural network consisting of one input layer with 10 inputs, one hidden layer with 600 neurons and one output layer with two outputs (cloud optical thickness and cloud top altitude). The network is trained with two years of CALIOP and SEVIRI data (July 2006 – June 2009). It uses the brightness temperatures of seven infrared channels and brightness temperature differences of SEVIRI (6.2, 7.3, 8.7, 9.7, 10.8, 12.0, 13.4 µm) and some auxiliary datasets (latitude, viewing zenith angle, and land-sea-mask) as input. The training and validation of the COCS algorithm was achieved with the COD and CTH derived from the 5 km cloud layer product of CALIOP.

Figure 3 shows a comparison of the COD derived by COCS (red) and by CALIOP (black) for the 18th Oct. 2008, 09:40 - 10:20 UTC (Kox, 2010). The overall agreement is very good. Both algorithms derive a COD of zero for cloud free areas. In cloudy areas the COD derived by COCS coincide well with the COD of CALIOP. Kox et al. (2010) remark, that the spatial variation of the COD derived by COCS is less than that one derived by CALIOP. He explains this behavior with the different spatial resolution of the two sensors. Kox et al. (2010) also mention some difficulties for retrieving the COD for latitudes larger than 60°. Larger deviations of the derived COD from passive imagers for high viewing zenith angles are also known from the CREW inter-comparison, see the CLOUDSTATE fellowship report 2011 (Hamann, 2011).

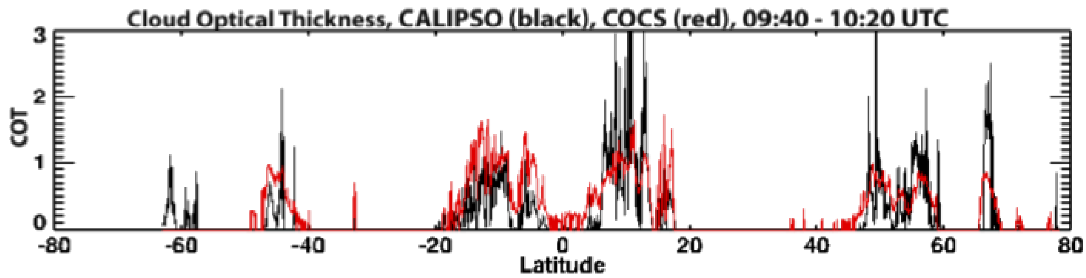


Figure 3: Comparison of the Cirrus Optical Depth (COD) derived by the COCS (red) and by CALIPSO (black) for the 18th Oct. 2008, 09:40 - 10:20 UTC, figure from Kox et al. (2010).

Figure 4 shows the same comparison of COCS and CALIOP as figure 3, but for CTH. The overall agreement is very good. Kox et al. (2010) report some uncertainties in retrieving CTH for clouds with COD ≈ 0.1. Comparing figure 3 and 4, it can be observed that the CTH observed by CALIOP shows rather flat cirrus tops, where the COCS dataset seems to have a remaining influence of the COD, where low CODs correspond to a minor underestimation of the CTH.

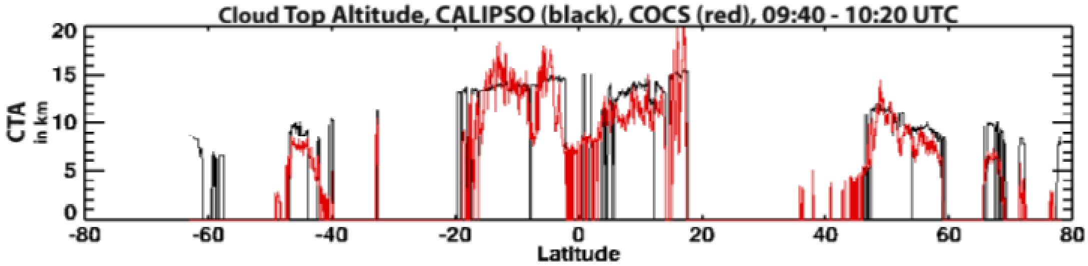


Figure 4: Comparison of the Cirrus Top Altitude (CTA) derived by the COCS (red) and by CALIPSO (black) for the 18th Oct. 2008, 09:40 - 10:20 UTC, figure from Kox et al. (2010).

In order to determine the validity the COCS datasets, the Eumetsat fellow compared this dataset with other datasets of the CREW database. Five other retrieval algorithms provide CTH data: CM SAF (CMS), Meteo France (MFR), University of Madison Wisconsin (AWG), UK Metoffice (UKM), and NASA Langley Research Centre (LAR). Figure 5 shows the inter-comparison of those retrievals. The comparison is limited to ice clouds, as COCS works only for this cloud type at the moment. The first point to mention is the different extent of the ice clouds. The ratio of satellite pixels classified as ice clouds to the total number of pixels is 11% for the CMS, 23% for MFR, 26% for AWG, 22% for UKM, 18% for LAR, and 32% for COCS. The ice cloud cover of CMS is remarkably lower than the other datasets. The COCS algorithm trained especially for the detection of ice clouds retrieves the highest ice cloud cover.

After examining the ice cloud cover, we examine the CTH itself. The mean cloud top height of the CMS, MFR, and LAR is similar around 10 km. The mean CTH of UKM is 7.5 km and thus 2.5 km lower than the three aforementioned algorithms. The UKM algorithm classifies many pixels over the southern Atlantic as ice clouds with very low CTH, that are not classified as ice clouds by all other algorithms. Therefore is it likely, that UKM algorithm has some problems with the phase determination of water clouds over the ocean, which in consequence explains the low CTH mean. The CTH derived by COCS is about 2.5 km higher than the mean CTH of CMS, MFR, and LAR. This difference can partly be explained by the construction of the remote sensing algorithms. Radiative transfer calculations reveal that the brightness temperature seen by the SEVIRI satellite originates mainly from a COD of about 1, whereas COCS is trained with CALIOP data, being able to detect very thin clouds with extinction coefficients of about 0.05 / km. It is expected that CALIOP detects a much higher CTH than SEVIRI in the following situations: (1) for a one layer cloud with a COD < 1, especially when the geometrical extent of the cloud is large, and (2) for a multi layer cloud system, where the uppermost cloud layer has a COD < 1. The same effect probably contributes to the 1 km larger mean CTH of AWG compared to CMS, MFR, and LAR, as CALIOP data is used in the design of the AWG algorithm.

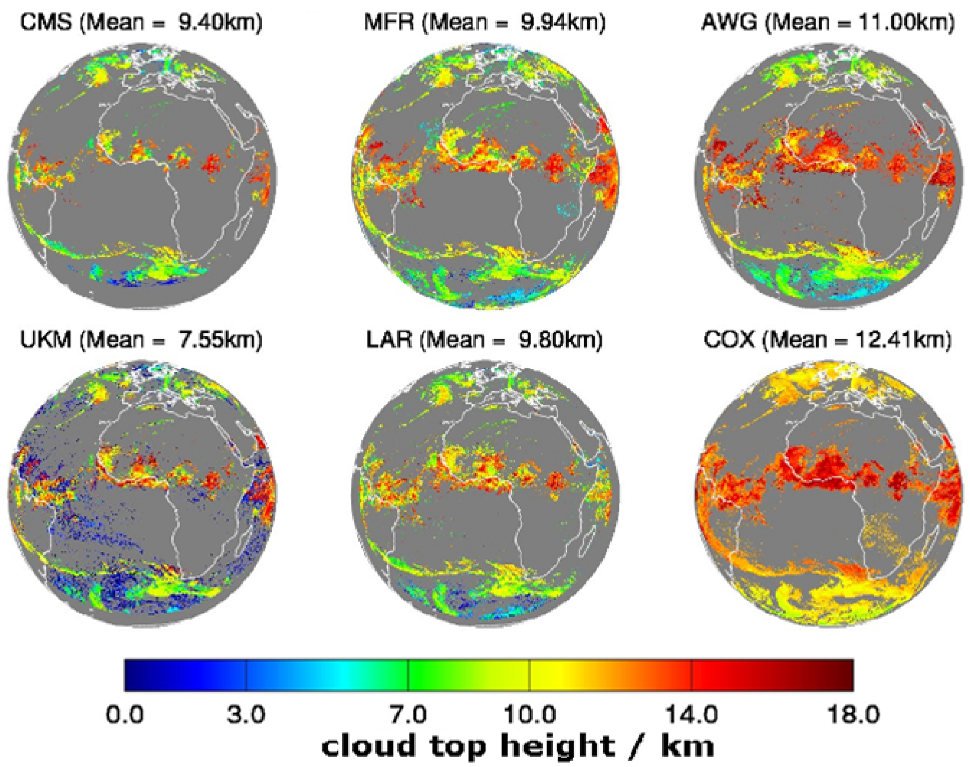


Figure 5: Inter-comparison of the Cloud Top Height of ice clouds for 13-06-2008 at 12:00UTC. The groups are CM SAF (CMS), Meteo France (MFR), Univeristy of Madison Wisconsin (AWG), UK Metoffice (UKM), and NASA Langley Research Centre (LAR), and the COCS algorithm from the DLR (COX).

In figure 6 we show the same region as we examined in figure 2, but with emphasis on the COCS dataset. We observe that the COCS algorithm derives values that are sometimes above the CALIOP measurement, in particular for the multi layer region and for the optically thick clouds. We expect this, as the neural network of the COCS algorithm was trained with CALIOP measurements. The unavoidable residual between the COCS and CALIOP dataset should ideally be evenly distributed around 0. On the contrary for all algorihms discussed in chapter 3.1, it is expected that the retrievals return a CTH close to an optical depth of 1, and therefore the expected CTH is lower than the CALIOP measurement. For the thin cirrus region, the COCS retrieval is tendencially below the CALIOP CTH and in the vicinity of the uppermost results of the other SEVIRI retrievals.

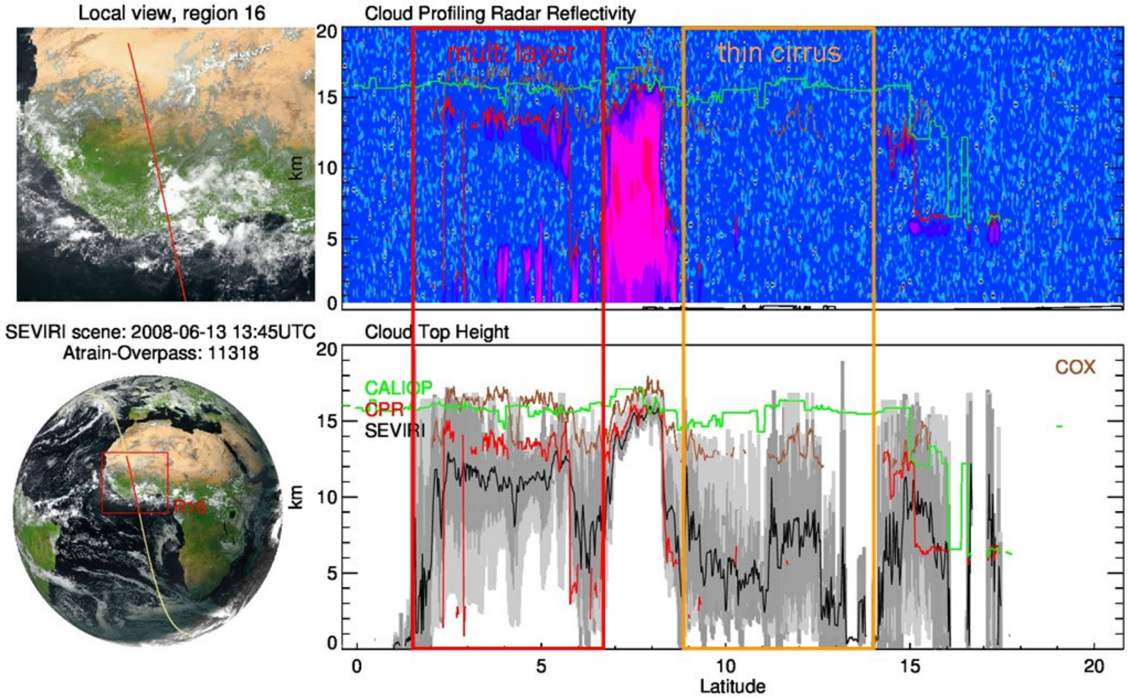


Figure 6: Same picture as figure 2, but showing the COCS retrieval. The standard deviation of all other algorithms is shown in dark grey and the minimum/maximum range in light grey.

3.3 The second cloud layer product of the OCA algorithm

In this chapter we focus on an additional product of the OCA algorithm (Watts, 2011a). The OCA algorithm is capable of deriving the cloud physical properties of a possible second cloud layer, which may be present under another cloud layer. This feature is unique among the retrieval algorithm ensemble submitted to the CREW database. The OCA algorithm is an optimal estimation algorithm using the 6.2, 7.3, 8.7, 9.6, 10.8, 12.0, and 13.4 µm channel of the SEVIRI sensor. The OCA retrieval works as follows: In the first run of the optimal estimation schema, the cloud optical depth, the effective radius, and the cloud top pressure for a single layer cloud are derived simultaneously. If the residual of the optimal estimation gets small enough, it is assumed that the cloud situation can accurately be described with a single cloud layer. But if the residual becomes smaller than a certain threshold, the OCA algorithm assumes, that the assumption of a homogeneous one layer cloud is not valid, and a second optimal estimation run is started. So a second modified run of the optimal estimation is started. This time, the surface skin temperature is used as a proxy for the cloud top temperature of a second lower cloud layer. Figure 7 (Watts, 2011b) illustrates the approach of the OCA algorithm for multi layer clouds.

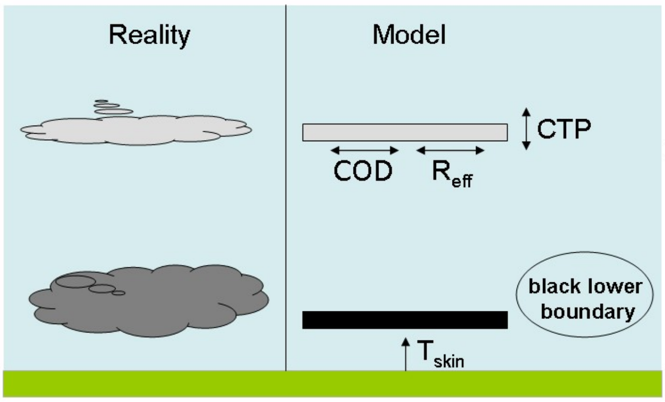


Figure 7: Illustration of the approach to derive the cloud top temperature a second cloud layer as realized in the OCA algorithm of Phil Watts (illustration by Watts 2011b, slightly modified).

In figure 8 we reexamine the cloud sitation of figure 2 focussing on the OCA products. For the multi layer situation the upper OCA cloud top pressure is close to the CPR measurement. The cloud top of the second cloud layer follows closely the CPR backscatter signal of the lower layer. This shows that the OCA approach of Watts is very promising. In the area with thin cirrus clouds, the OCA algorithm occasionally detects a second cloud layer, which might be possible as CPR occasionally detects a second cloud layer, too. In these cases the upper cloud top of OCA is above the mean of the SEVIRI algorithms and closer to the CALIOP measurement. In case of a single layer retrieval the cloud top of OCA is close to the mean of all SEVIRI algorithms.

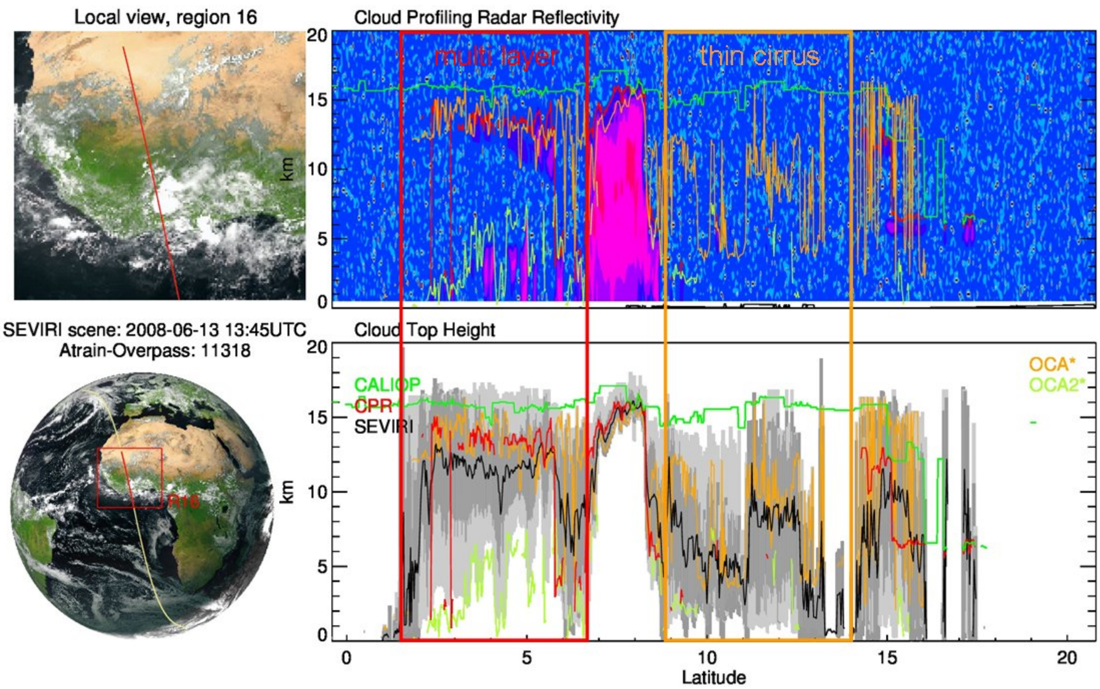


Figure 8: Same picture as figure 2, but showing the products of the OCA retrieval. The first cloud layer is labeled with OCA, the product of the possible second cloud layer as OCA2. The standard deviation of all other algorithms is shown in dark grey and the minimum/maximum range in light grey.

3.3 Priliminary assessment of cloud parameter error estimates

There are plans to investigate the error estimate of the retrievals at the 4th CREW next year. The uncertainty estimate of the individual algorithms will be compared to the spread of the multi algorithm ensemble. Ideally the spread of the algorithm results should be small, when the error estimates of the individual algorithms is small, too. In this section we present a preliminary assessment of error estimates. We compare the error estimates as calculated by the OCA algorithm with the standard deviation of the multiple algorithm ensemble.

The retrieval uncertainty for many cloud physical parameters is dependent on the cloud optical depth. For example, a common method for the retrieval of the cloud optical depth and effective radius is the Nakajima-King approach (Nakajima, 1990) using one channel in the visible and one in the near infrared wavelength region. The relation of the cloud optical depth and the effective radius on the reflectivities is illustrated in figure 8. The reflectivity of the absorbing channel increases less than the reflectivity of the non-absorbing channel with increasing optical depth. The near infrared channel has also a stronger sensitivity to the particle size as the non-absorbing channel. In figure 8 the uncertainty of the reflectivities is schematically represented by a grey and a red shaded area. For clouds with a small optical depth, it is obvious that reflectivities of clouds with different effective radii are very similar. Furthermore, the bidirectional reflectance distribution function of the earth surface, that itself is not perfectly known, influences reflectivities for small optical depths. Therefore, we expect a large uncertainty of the effective radius, when the optical depth is small. For optically thick clouds, the change of the reflectivities with increasing optical depth is very small, but the reflectivity of the absorbing channels depends strongly on the effective radius. Hence, we expect a high uncertainty for the retrieved optical depth and low uncertainty for the effective radius.

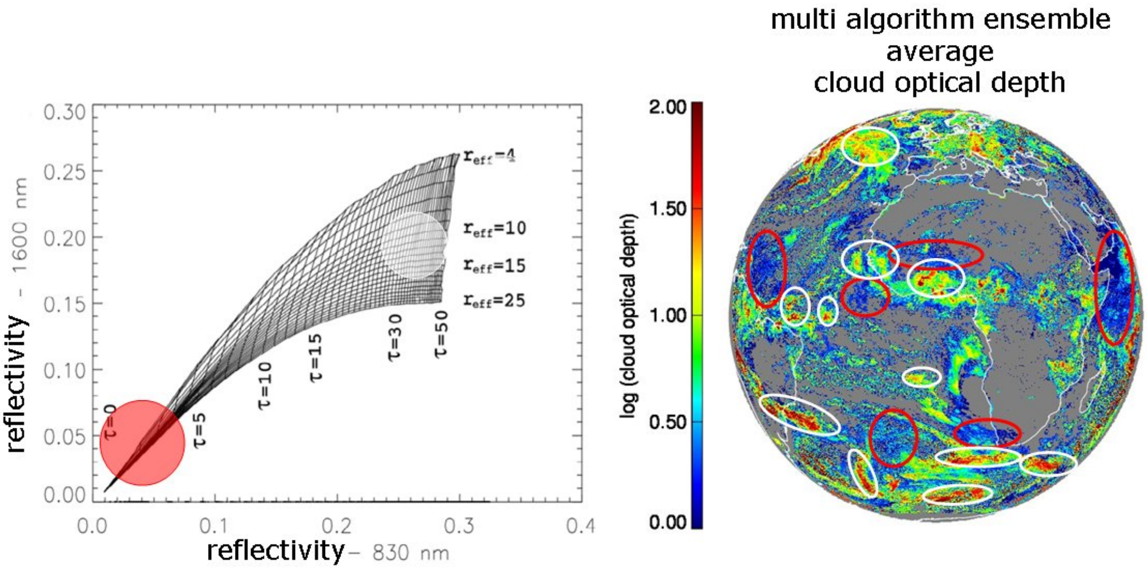


Figure 8: The left figure illustrates the effect of effective radius and cloud optical depth on the reflectivity of one non-absorbing channel (here 830nm) and one absorbing channel (here 1600nm), modified from Zinner (2005). This dependence is used by the the Nakajima-King method in order to retrieve the two cloud properties. Two uncertainty regimes are marked: In red the uncertainty for optically thin clouds and in white for optically thick clouds. On the right hand side the multi algorithm ensemble average of the cloud optical depth is plotted for 13-06-2008 at 12:00UTC. The corresponding uncertainty regimes are marked in the same colors as in the Nakajima-King plot.

In the following we examine the standard deviation of the CREW algorithm ensemble and the error estimate of OCA algorithm. These datasets are different means to estimate the uncertainty of the retrieved effective radius. The error estimate of the OCA algorithm is based on the residual of the optimal estimation retrieval. Therefore, the algorithm takes into account the uncertainty of the satellite measurement, the estimated effect of cloud inhomogenity and the surface reflectivity, but does not include the uncertainty of some retrieval assumptions like details of the parametrization of the optical properties of the cloud particles, in particular the choise of the ice crystal shape, remaining uncertainties from trace gase and temperature profiles as well as aerosols. In case that different assumptions were made in the different cloud retrievals, the standard deviation of the multi algorithm ensemble include these kinds of uncertainties. In case that all retrievals make the same assumption, the uncertainty of this assuption is not reproduced in the algorithm standard deviation neither. Considering this, we do not expect a one-to-one correspondance of the OCA uncertainty estimates and the multi algorithm standard deviation, but nevertheless a positive correlation.
Figure 9 shows the standard deviation of the effective radius of the CREW algorithm ensemble on

the left hand side and the error estimate of the OCA algorithm on the right hand side. The same areas with optically thin clouds as in figure 8 are marked. Both datasets indicate large uncertainties in the marked regions with optically thick clouds, as the discussion of the Nakajima-King suggests. At the southern edge of the SEVIRI disk there is a sharp increase of the uncertainty estimate of OCA. During the time of the observation, 2008-06-13 12UTC, the sun is close to or below the horizon in this region. Hence, the OCA algorithm does not make use of the solar channels, and in consequence the uncertainty of the retrieval is larger in this region compared to the rest of the disk. The multi algorithm standard deviation increases here, too, but with a less sharp transition, as the retrieval algorithms have different cutoff thresholds of the solar zenith angle for the usage of the solar channels. Both datasets show that the effective radii in marine strato-cumulus regions west of Angola and in the North Atlantic as well as over tropical Africa can be retrieved with the lowest uncertainty. In this region, the clouds are mainly water clouds. The retrieval of the effective radius of water dropelts is easier than the one for ice crystals, as the shape of water droplets is well known, but there are various types of ice crystals and the assumptions in the retrieval methods of the ice crystal shape may differ. Another reason for the low retrieval uncertainty in these regions is the horizontal homogenity of the marine strato-cumulus. Therefore no pronounced effects of the three dimensional radiative transfer or subpixel inhomogenities are expected here.

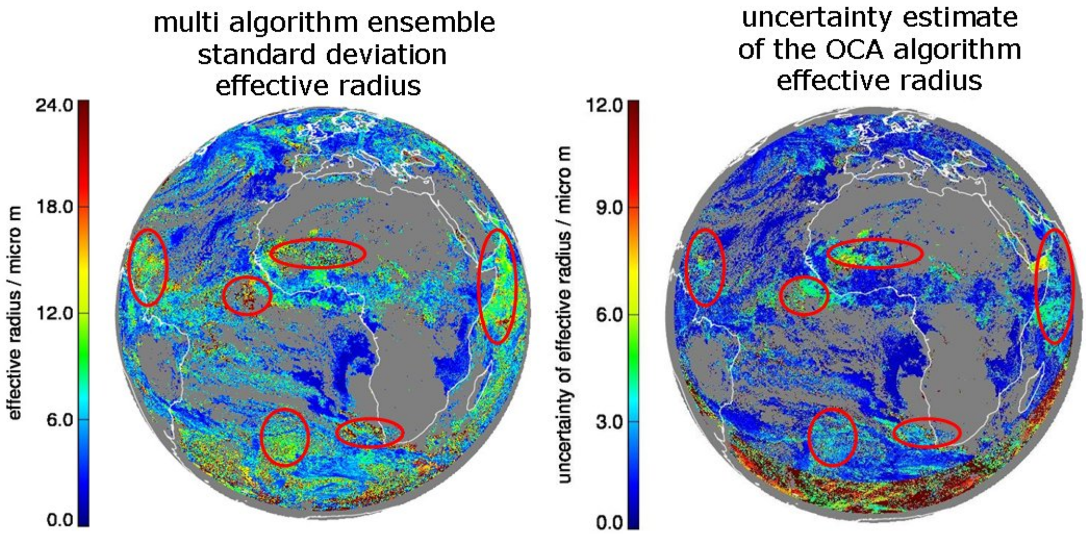


Figure 9: The left hand side shows the multi algorithm ensemble standard deviation of the effective radius for 2008-06-13 12UTC. On the right hand side the uncertainty estimate of the OCA algorithm is shown. The same areas of low optical depth as in figure 8 are marked.

In figure 10, we examine the error estimates of the cloud optical depth. The multi algorithm standard deviation is shown on the left hand side and the error estimate of the OCA algorithm on the right hand side. As expected from the discussion of the Nakajima-King method, the uncertainty for the retrieved cloud optical depth is largest for optically thick clouds, compare the marked areas in figure 8 and 10. This effect can be observed for both the OCA error estimate and the multi algorithm standard deviation. Furthermore, the both uncertainties raise at the southernmost part of the SEVIRI disk for the same reason as for the effective radius, the lack of solar observations. Tendencially, lower retrieval uncertainties are noticed for clouds over the ocean. Possible reasons are the good contrast between clouds and the dark ocean and the well known reflection properties of the ocean. In contrast, the reflection properties of various land surface types vary much more.

In summary, we conclude that the uncertainty for the effective radius retrieval is largest when the optical depth is small. Furthermore the uncertainty is larger for ice clouds than for water clouds. The uncertainty for the cloud optical depth is largest for optically thick clouds. The retrievals for both cloud properties have a higher uncertainty, if no solar observations are available. All findings can be observed in the multi algorithm standard deviation and in the uncertainty estimate of the OCA retrieval.

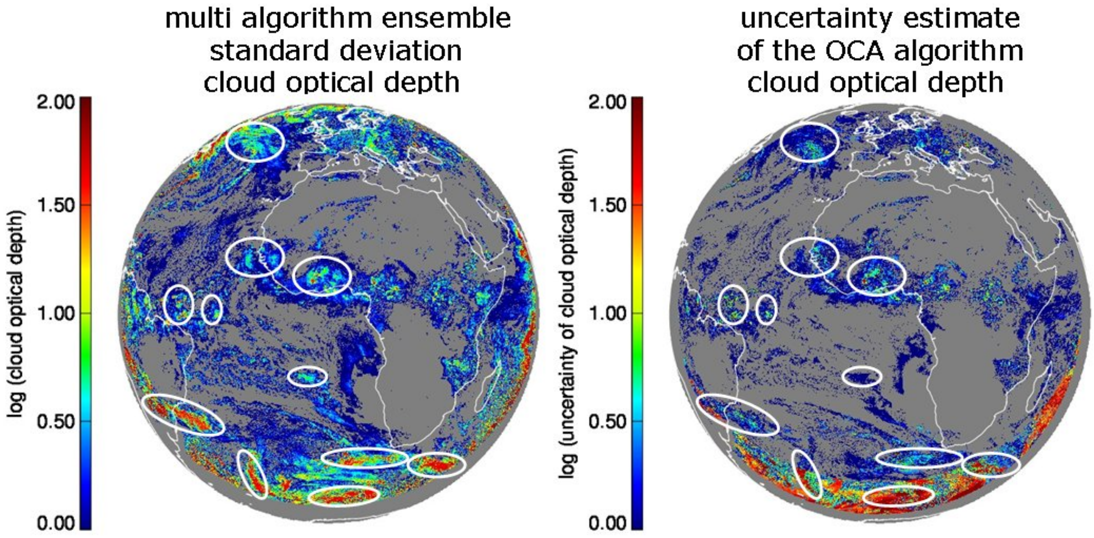


Figure 10: The left hand side shows the multi algorithm ensemble standard deviation of the cloud optical depth for 2008-06-13 12UTC. On the right hand side the uncertainty estimate of the OCA algorithm is shown. The same areas of high optical depth as in figure 8 are marked.

4. The 3rd year of the CLOUDSTATE fellowship

In the 3rd year of the CLOUDSTATE fellowship, the fellow will concentrate on publishing the results found so far. Some scientific investigation are nessesary in order to do so. The research of cloud top height products will be intersified as far as needed for the publication. The cloud detection limit of the different SEVIRI algorithms should be determined by investigating the probability of detection and false alarm rates in dependence of the CALIPSO cloud optical depth (provided that according changes are realized in an updated AVAC-S software). The publication of the results is planed in the peer reviewed journal AMT .

Research
First the fellow will extend the validation of the cloud top height of the SEVIRI algorithms as nessesary for a publication. Thereafter the fellow will investigate the ability of the algorithms to detect clouds in dependence of the CALIOP optical depth.

Common database and webpage
Reports, publications and annoucements of the 4th CREW will be published on the CREW website. If new or updated retrieval datasets are available, they will be included in the common database.

Papers and Reports
A publication of the cloud top height validation in AMT is in progress. Another publication about the cloud detection also in AMT is aspired. The third yearly fellowship report for Eumetsat will be submitted.

Contributions to 4th CREW
The Eumetsat fellow will provide scientific support for the 4th CREW. He will contribute to a report written in preparation to the workshop. In consultance with the supervisors the support of the fellow will be limited in order to allow the fellow to concentrate on the publications. For a full support for 4th CREW by the fellow, additional funding for the time until the workshop is nessesary. It would be very benefitial for the Cloud Retrieval Evaluation project, if the fellow can stay involved at least until the 4th Cloud Retrieval Evaluation Workshop in March 2014.

Meetings and Presentations
The results of the fellowship will be presented at the *EUMETSAT Conference* 2013 in Vienna, Austria. If the job situation of the fellow allows, the fellow will participate the *EUMETSAT fellow day* in December 2013.

5. The 4th CREW in March 2014

The Cloud Retrieval Evaluation Workshops are organized regularly in order to discuss to progress of cloud remote sensing and the newest results of the CREW inter-comparison. In 2006, the 1st workshop located in Norrköping, Sweden, had about 19 participants. The 2nd workshop in 2009 located in Locarno, Switzerland had about 42 participants. Finally 71 scientists participated the 3rd CREW. The participants of the 3rd Workshop in Madiason proposed to have a further meeting. **The 4th Cloud Retrieval Evaluation Workshop will be realized 4 – 7 March 2014 in Grainau, southern Germany.** The DWD offered to manage the local organization.

An integral part of the CREWs are the discussions on inter-comparison and validation studies done with the data from the common database. In this way knowledge is gained on the behavior of the different retrieval schemes over different cloud conditions.

The main recommendations of the 3rd CREW in Madison for future work were:

- Address the focal points of the GEWEX-Cloud Assessment;
- Address research questions on level-2 cloud retrieval methods:
  - multiple layer cloud detection methods;
  - infrared-only cloud parameter retrieval methods;
  - microphysical properties of ice cloud models;
- Assessment of level-2 cloud properties retrievals and their error estimates;
- Improve on methods to aggregate level-3 cloud products;
- Enhance traceability and uniformity of level-3 cloud products;
- Establish sub-working groups addressing specific research topics;
- Involve other space agencies as well as participants from Asia and Australia;
- Establish CREW as working group under the umbrella of GEWEX and/or CGMS.

As the 4th CREW happens after the end of the CLOUDSTATE fellowship, it would be beneficial that the EUMETSAT fellow may stay involved until the results of the 4th CREW are summarized.

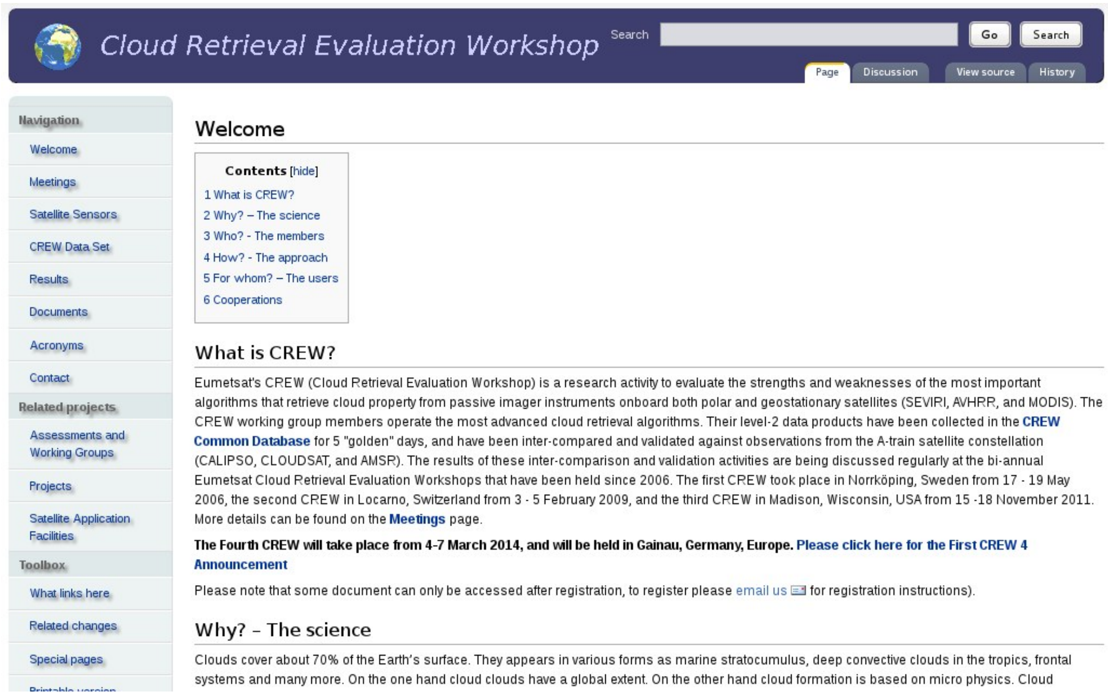
6. Documentation of the CREW project

The CREW project - including the objectives of CREW, the participating institutions, description of datasets and retrieval methods, reports of the meetings, and presentations of the participants - is documented on the CREW project website:

http://www.icare.univ-lille1.fr/crew/

Furthermore, the CREW database consisting of 12 SEVIRI algorithms and reference datasets is available for CREW participants via the CREW website or the ICARE ftp webserver:

ftp://ftpush.icare.univ-lille1.fr/crew/data



Acronyms

AMSR-E	Advanced Microwave Scanning Radiometer for EOS
AMT	Atmospheric Measurement Techniques (peer reviewed journal)
AVHRR	Advanced Very High Resolution Radiometer
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarisation
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CLOUDSAT	Cloud satellite mission operated by NASA
CM SAF	Satellite Application Facility on Climate Monitoring
COCS	Cirrus Optical properties derived from CALIOP and SEVIRI
CPP	Cloud Physical Properties algorithm
CPR	Cloud Profiling Radar
CREW	Cloud Retrieval Evaluation Workshop
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
KNMI	Koninklijk Nederlands Meteorologisch Instituut
METEOSAT	Meteorological satellite
MISR	Multi-angle Imaging SpectroRadiometer
MSG	Meteosat Second Generation
MODIS	Moderate Resolution Imaging Spectroradiometer (NASA/Terra, Aqua)
POLDER	POLarization and Directionality of the Earth's Reflectances
SEVIRI	Spinning Enhanced Visible and Infrared Imager

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