# COCS – CIRRUS OPTICAL PROPERTIES DERIVED FROM CALIOP AND SEVIRI DURING DAY AND NIGHT TIME

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**Abstract**

Significant progress in cirrus cloud observation has been achieved with spaceborne active remote sensing techniques, e.g. the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) aboard the polar-orbiting Cloud-Aerosol Lidar and Infrared Pathfinder Satellite (CALIPSO). With its high vertical and horizontal resolution CALIOP provides high detailed profiles of optical properties especially of cirrus clouds.
But to deliver information on the lifecycle of cirrus clouds high temporal resolution is needed. These observations are performed by the Spinning Enhanced Visible and Infrared Imager (SEVIRI) aboard MSG every 5-15 minutes providing high detailed information (e.g. brightness temperatures of seven infrared channels) making a day and night time observation of clouds possible.
In the following, the COCS algorithm (Cirrus Optical properties derived from CALIOP and SEVIRI) combining the advantages of both satellite instruments, some preliminary results, intercomparisons and examples of its application are presented. COCS provides the cloud optical thickness (COT) and the cloud top altitude (CTA) of cirrus clouds.

## INTRODUCTION

Cirrus clouds have a substantial impact on the radiation budget of the earth and therefore on climate. However, their representation in climate prediction models is still suffering from a lack of knowledge. For a better understanding, especially of thin cirrus clouds, the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission was launched in April 2006 providing global observations of aerosols and clouds with its Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP, [Winker et al, 2002]).
In this work the cloud layer product with an along track resolution of 5 km and a swath width of 90 m is used. Since CALIPSO flies as a part of the National Aeronautic and Space Administration (NASA) afternoon constellation, injected into a polar orbit of 705 km altitude with a repeat cycle of 16 days, its temporal resolution is limited.
But a high temporal resolution is needed to observe atmospheric processes like lifecycle, diurnal cycles and evolution of cirrus, which is provided by the Spining Enhanced Visible and InfraRed Imager (SEVIRI) aboard MeteoSat Second Generation (MSG, [Schmetz et al, 2002]). This instrument combines the ability to observe earth's atmosphere during day and night time due to its infrared channels (e.g. 6.2 – 13.4 $\mu$m) with its high temporal resolution of 5 – 15 minutes for a whole „disc" covering a latitude from around 80°S to 80°N and a longitude of 80° W to 80° E.
In this work a new approach will be presented to combine the advantages of both instruments in a retrieval based on a Neural Network, called COCS, Cirrus Optical properties derived from CALIOP and SEVIRI during day and night time.

## COCS – CIRRUS OPTICAL PROPERTIES DERIVED FROM CALIOP AND SEVIRI

As mentioned before COCS is based on a Neural Network. It consists of one input layer with 12 inputs (infrared brightness temperatures of SEVIRI and auxiliary data), one hidden layer with 200 neurons and one output layer with 2 outputs (cloud optical thickness and cloud top altitude).

The cloud optical thickness (COT) of CALIOP is defined as

$$\tau = \int_{z_1}^{z_2} \alpha \; dz \quad ,$$

where $\alpha$ is the extinction coefficient retrieved from CALIOP backscatter measurements [Vaughan et al., 2005, 2008], $z_1$ is the bottom of the cirrus layer and $z_2$ its top. While SEVIRI retrieves brightness temperatures with no vertical informations, CALIOP delivers vertical profiles of earth's atmosphere and is able to penetrate through non-opaque cloud layers. So, if CALIOP detects more than one layer of non opaque cirrus clouds (defined as clouds with temperatures lower than 236,15 K), the COTs of each layer are integrated.

## INPUT AND TRAINING DATASET

To achieve a training dataset for the Neural Network, 2 years of CALIOP and SEVIRI data (July 2006 – June 2008) were used:

- Brightness temperatures of the seven infrared channels of SEVIRI (6.2, 7.3, 8.7, 9.7, 10.8, 12.0, 13.4 $\mu$m)
- Auxiliary datasets (day of the year, latitude, viewing and solar zenith angle, land-sea-mask)
- Cirrus optical thickness (COT) and cirrus top altitude (CTA) derieved from the 5 km cloud layer product of CALIOP

For this dataset a spatial and temporal collocation is done.
The spatial collation is done in two ways. On the first hand a parallax correction is applied to the SEVIRI data taking into account its viewing geometry. This parallax correction applied to the collocated SEVIRI pixels uses the top altitude of those cirrus clouds detected by CALIOP. On the second hand latitude and longitude of the CALIOP data were collocated with the fitting pixels of SEVIRI (nearest neighbor) due to the different spatial resolutions of SEVIRI (3 x 3 km$^2$ NADIR) and CALIOP (5 km along track).
The temporal collocation is done due to the different sampling times of SEVIRI compared to the CALIPSO overpasses.
As explained in the CALIPSO Quality Statements for the Lidar level 2 cloud and aerosol profile products some artifacts are present in the retrieval algorithm for cloud optical thickness (COT) when a reduction of the lidar ratio is applied by the algorithm, which often happens at opaque cirrus clouds [Kusterer, 2009].
Therefore only the CALIOP data with the highest quality flag are used in the training dataset for COCS and the COT is limited to non-opaque features with $\tau \leq 3$ . Furthermore some filtering has to be done due to some artifacts concerning aerosol (especially over tropical oceans) detected as cirrus clouds in very low altitudes.

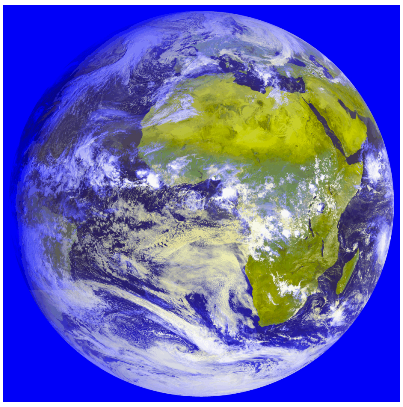

Figure 1.1: SEVIRI – RGB, MSG 8,DLR-EUMETSAT, 18/10/2008, 09:30 – 10:15 UTC

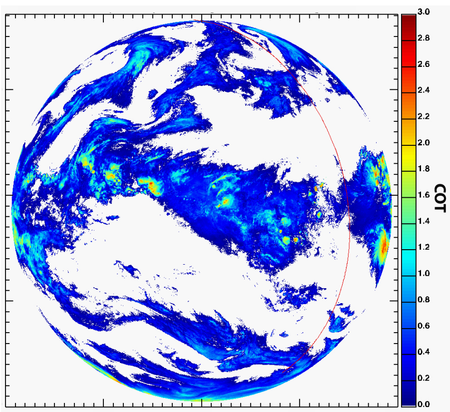


Figure 1.2: COCS – COT, 18/10/2008, 09:30 – 10:15 UTC

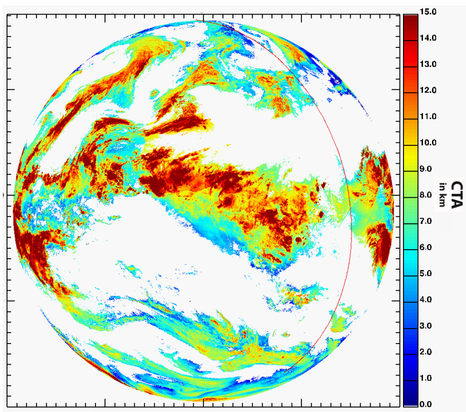


Figure 1.3: COCS - TOP, 18/10/2008, 09:30 - 10:15 UTC

## OUTPUT

After finishing the training of the Neural Network, COCS is applied to SEVIRI images taken every 15 minutes. COCS is only sensitive to cirrus clouds with a COT of 0.01 to 3. The minimum threshold is set to prevent a high false alarm rate due to coarse sensitivity of SEVIRI to very thin cirrus compared to CALIOP.
In Figure 1.2 the derived COT is shown for a composition of four images of SEVIRI (09:30 – 10:15 UTC, Figure 1.1). Beside two tropical cyclones in the western region some convective systems are visible over Africa with cloud optical thicknesses up to a value of $\tau$=3. A field of cirrus clouds with very low COTs is detected over the Gulf of Guinea covering the area between those convective systems. Even the frontal systems at higher and lower latitudes are present with lower COTs. .
Figure 1.3 shows the cirrus top altitude (CTA) in kilometers for the same image. The CTA reaches up to 15 km in the tropics while it is only a few kilometers for higher and lower latitudes.
Some artifacts are visible due to the outer limits of the cirrus cloud field over Africa where the COT is low and the CTA is computed with a value of only 4-5 km.

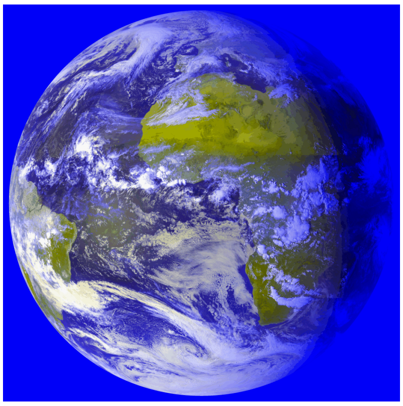

**Figure 2.1: SEVIRI – RGB, MSG 8, DLR-EUMETSAT, 18/10/2008, 14:30 – 15:15 UTC**

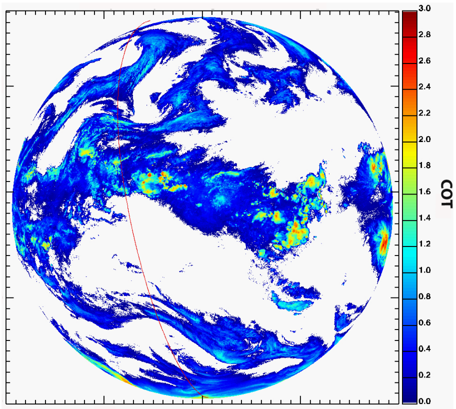


**Figure 2.2: COCS – COT, 18/10/2008, 14:30 – 15:15 UTC**

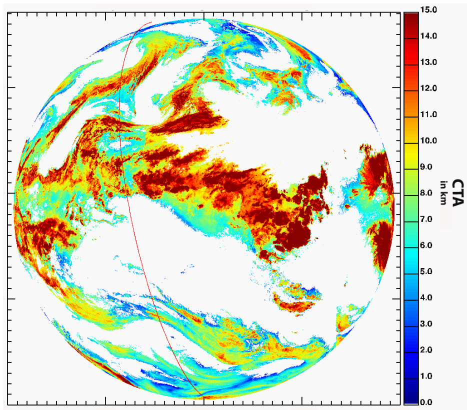


**Figure 2.3: COCS - TOP, 18/10/2008, 14:30 - 15:15 UTC**

Another is example is given in Figures 2.1, 2.2, 2.3 (14:30 – 15:15 UTC). In Figure 2.2 an evolution of the thunderstorms within the tropical convergence zone compared to Figure 1.2 is obvious with raising COTs over eastern Africa, as well as the slow movement of the frontal system in the higher and lower latitudes. The tropical cyclones located in the western part of the image are still present, while the COTs of the northern one are measured with slightly lower values.
The CTA shows a similar behaviour. There are more CTAs over eastern Africa raising up to 15 km .
The frontal systems with their high and low altitude cirrus clouds are detected in a range of 6 - 12 km .

## INTERCOMPARISON WITH CALIOP

In order to compare CALIOP with the COCS algorithm, vertical integrated cloud optical thicknesses and cloud top altitudes are plotted against the result of COCS along the CALIOP track.
Both cases are taken from the $18^{th}$ October 2008 and are consequently independent form the training dataset.
In Figure 3.1 the COT and in Figure 3.2 the CTA of the CALIOP overpass at 09:40 – 10:20 UTC (marked as red lines in Figure 1.2, 1.3) are shown. The corresponding results of COCS are plotted in red, while CALIOP data are plotted in black.
In this first case, obviously only one feature at -60° latitude remains undetected, while all other cirrus clouds are detected by COCS. Large areas of the overpass are free of cirrus clouds resulting in a COT equal to 0. COCS fails to follow the narrow peaks in the CALIOP COT (e.g. at 0°-20° latitude) and therefore underestimates those strong peaks.
Each pixel of SEVIRI covers at least 9 $km^2$ (NADIR), while CALIOP retrieves the backscatter profiles over an area of 0.45 $km^2$. This shows, that SEVIRI is unable to detect such strong and fast changes in the COT as CALIOP does.
Nevertheless COCS detects the features and follows those peaks of the CALIOP cloud optical thickness.

A slightly different behaviour show the cloud top altitudes in Figure 3.2. COCS detects the CTA of cirrus clouds with only small deviation from the CALIOP measurements with small overestimations (e.g. at -20°-0° latitude) and small underestimations (e.g. 0°-15° latitude).

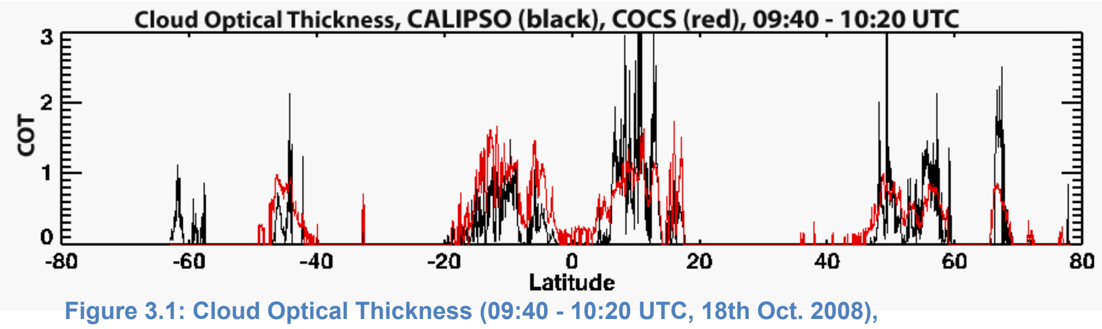


Figure 3.1: Cloud Optical Thickness (09:40 - 10:20 UTC, 18th Oct. 2008), CALIPSO (black), COCS (red)

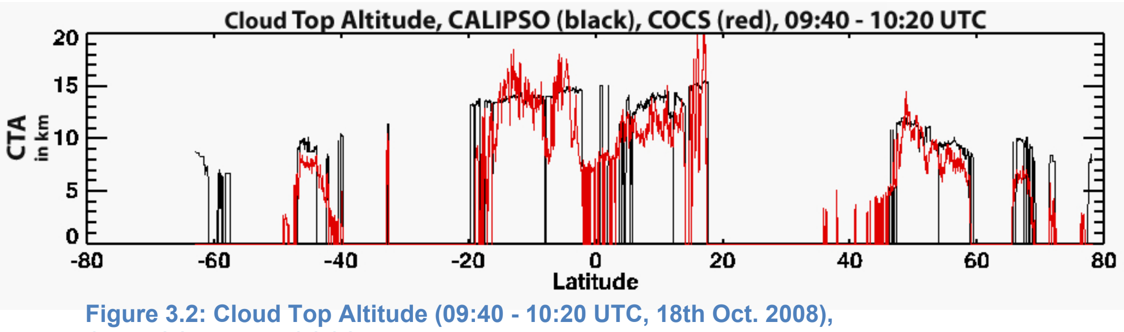


Figure 3.2: Cloud Top Altitude (09:40 - 10:20 UTC, 18th Oct. 2008), CALIPSO (black), COCS (red)

The second case is the overpass of CALIPSO from 14:36 – 15:12 UTC. In Figure 4.1 COCS shows very good results for latitudes greater than -30°. Even with a parallax correction in the training dataset, a high false alarm rate and a low detection efficiency is obvious for latitudes lower than -60°.
So, the very low COTs, especially for latitudes between -30° and +40°, show a very good correlation, while there are differences at higher and lower latitudes. The plot of the CTA in Figure 4.2 shows a deviant behaviour. While the thin cirrus clouds at latitudes -30° to +30° are underestimated by COCS, cirrus clouds at low latitudes from -80° to -30° are retrieved in good agreement with CALIOP measurements. The same happens to clouds at higher latitudes from +30° to +80°.

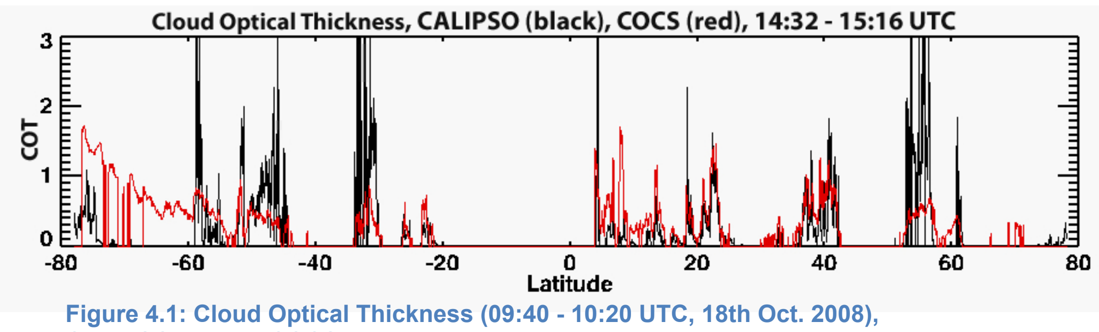


Figure 4.1: Cloud Optical Thickness (09:40 - 10:20 UTC, 18th Oct. 2008), CALIPSO (black), COCS (red)

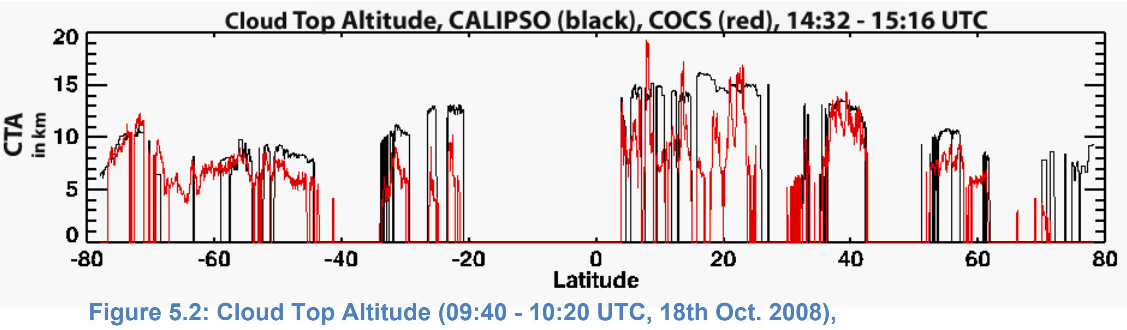


Figure 5.2: Cloud Top Altitude (09:40 - 10:20 UTC, 18th Oct. 2008), CALIPSO (black), COCS (red)

## CONCLUSION AND OUTLOOK

COCS, Cirrus Optical Properties derived from CALIOP and SEVIRI, is a fast algorithm that is sensitive to cirrus clouds with an optical depth $\tau \leq 3$. It is based on a Neural Network trained with a 2 year dataset of collocated and filtered CALIOP and SEVIRI measurements.
The algorithm can be applied to retrieve optical properties of thin cirrus clouds like cloud optical thickness (COT) and cloud top altitude (CTA).
The preliminary results and first independent intercomparisons with cirrus cloud measurements of the spaceborne Lidar CALIOP show good agreement and will be under detailed investigation in the future. Another intercomparison between the COCS and the Meteorsat Cirrus Detection Algorithm, MeCiDA [Krebs et al., 2007], will be part of future work as well as selected results of cirrus focused campaigns. Furthermore the training dataset will be extended to 3 years of data for a better statistical field and coverage (July 2006 – June 2009).

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