Optical properties of thin cirrus derived from the infrared channels of SEVIRI

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Abstract

Since April 2006 significant progress on the research and observation of thin cirrus clouds was achieved by the use of new remote sensing technologies aboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite (CALIPSO). With its high vertical and horizontal resolution the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) provides detailed profiles of optical properties especially of cirrus clouds and aerosol.
But to investigate the lifecycle of cirrus clouds high temporal resolution is needed. The Spinning Enhanced Visible and Infrared Imager (SEVIRI) aboard MSG every 5 - 15 minutes provides brightness temperatures for 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, first diurnal cycles of cirrus cloud ice optical thickness (IOT) and top altitude (TOP) are shown.

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 of thin cirrus clouds the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite (CALIPSO) was launched in April 2006 providing global observations of aerosols and clouds with ist Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP, [Winker et al, 2002]).
In this work the cloud layer product of CALIOP (Lidar Level 2, 5 km Cloud Layer Product) is used. It offers a 5 km horizontal resolution with a lidar footprint of around 90 m and a vertical resolution up to 30 m [Vaughan et al., 2008]. 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. Therefore its temporal resolution is rather limited. But to retrieve detailed informations of atmospheric processes like the lifecycle, diurnal cycles, and the temporal evolution of optical properties of e.g. cirrus clouds a high temporal resolution is essential. This high temporal resolution in combination with a good spatial resolution is provided by EUMETSAT's Spinning Enhanced Visible and InfraRed Imager (SEVIRI) aboard the geostationary MeteoSat Second Generation satellite (MSG, [Schmetz et al, 2002]). SEVIRI combines the ability to observe earth's atmosphere during day and night time due to its infrared channels (6.2 – 13.4 µm) with high sampling rates of 15 minutes for a "whole disc" covering an area of around 80°S to 80°N and 80°W to 80°E.

This work presents a new approach to combine both spaceborne observations in one retrieval based on a backpropagation Neural Network, called COCS, Cirrus Optical properties derived from CALIOP and SEVIRI during day and night time.

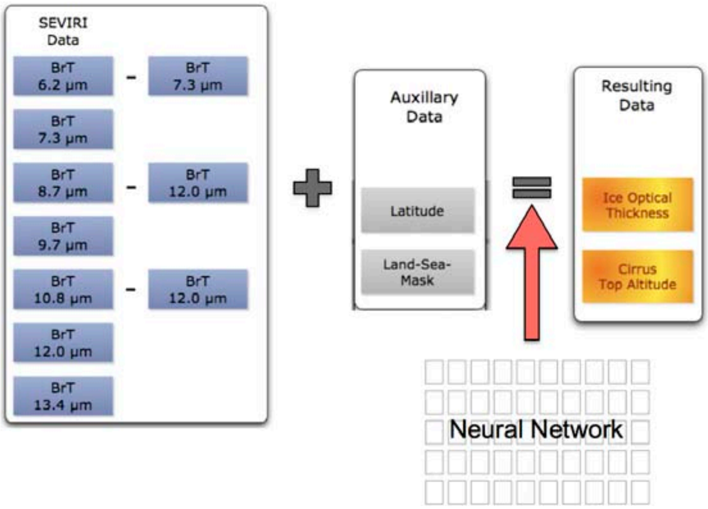

Figure 1: Schematic overview of COCS. Input layer on the left (SEVIRI data, auxiliary data) and the output layer on the right (resulting data).

COCS – Cirrus Optical properties derived from CALIOP and SEVIRI

COCS is based on a backpropagation Neural Network. This Neural Network derives the ice optical thickness (IOT) and the top altitude (TOP) of cirrus clouds from the infrared channels (IR) of SEVIRI. It consists of one input layer with 9 inputs (infrared brightness temperatures and auxiliary data), one hidden layer with 300 neurons, and one output layer with 2 outputs (IOT and TOP) as seen in figure 1.

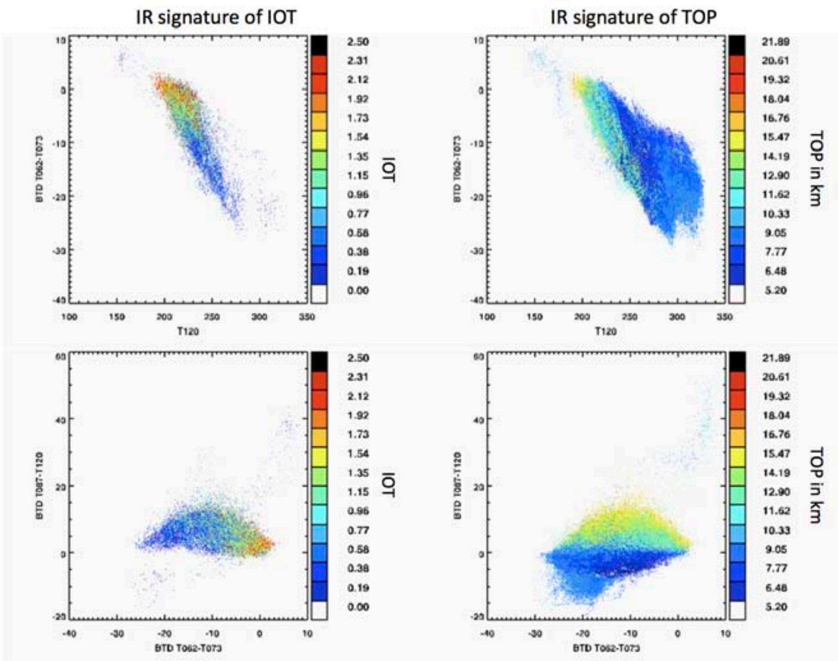

Figure 2: Exemplary IR signatures of IOT (left) and TOP (right) retrieved by CALIOP for different infrared channels of SEVIRI and their differences.

A backpropagation Neural Network always needs a ”training dataset“. Therefore the measurements of SEVIRI (brightness temperatures, BT) and the results of CALIOP have to be collocated in time and space. This collocation results in a dataset of more than 9.000.000 datasets (Figure 1) from July 2006 to June 2009. Due to the attenuation of the lidar beam of CALIOP, COCS is sensitive to ice optical thicknesses from 0.1 to 2.5.
The set of the infrared channel BT and BTD shown in Fig. 1 is chosen due to their different sensitivity to cirrus clouds as shown in Krebs et al, 2007.
Since infrared temperatures vary strongly over a wide range of ice optical thickness and top altitude of cirrus clouds the retrieval setup with a neural network was selected to solve this complicate relationship.
Different pairs of infrared brightness temperatures and/or differences are plotted in Figure 2, colour coded with IOT and TOP retrieved by CALIOP. For example, cirrus clouds with high IOT tend to have BTD of the 6.2 µm and the 7.3 µm cannel around zero, while the temperature of the 12.0 µm channel is very low (down to 200K). Thin cirrus clouds have a very low BTD while the temperature of the 12.0 µm channel is rahter high. For the top altitude a similar signature is obvious (Figure 2, upper left and right).
Another example is shown in Fig. 2, bottom left and right. Here again the BTD of the 6.2 µm and the 7.3 µm channel are around zero for high IOTs, while they get negative for thin cirrus clouds. The BTD of the 8.7 µm and the 12.0 µm channel remains around zero for thin and thick cirrus clouds, while the BTDs for the top altitudes vary in both cases.

A first validation of COCS is done with 1.078.582 vectors of SEVIRI and CALIOP measurements. These data were not used in the training and are therefore independent. The validation results in a standard deviation of IOT = 0.3 and TOP=0.8 km, shown in Figure 3.

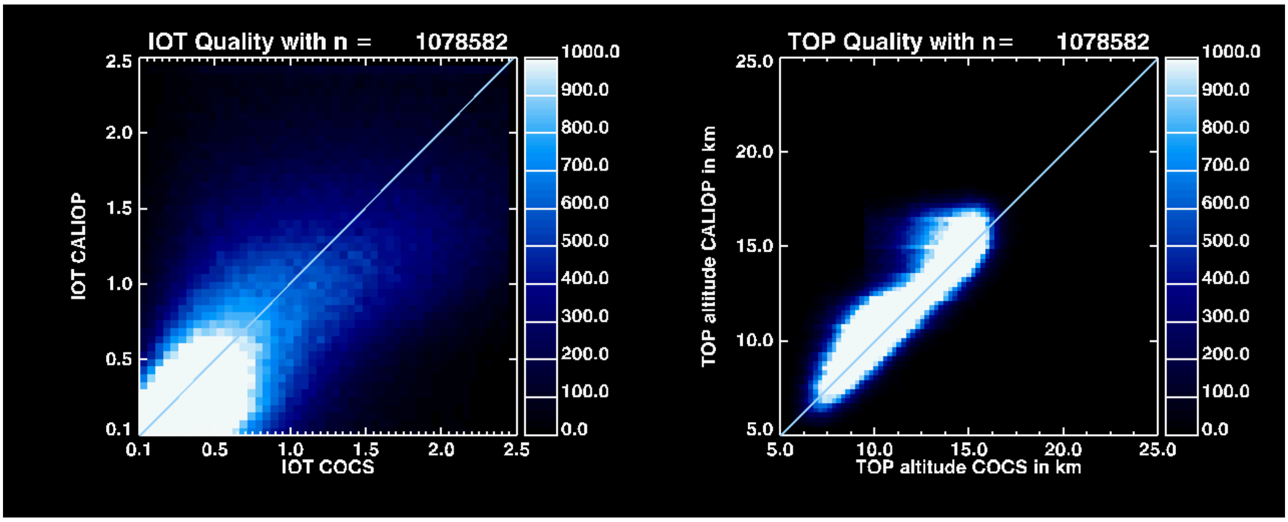

Figure 3: Validation of IOT and TOP using 1.078.582 independent results of COCS and measurements of CALIOP.

For further validation of COCS we use data of the LUAMI campaign [M. Wirth et al, 2008]. A scientific airplane, FALCON, of the German Aerospace Center (DLR) was carrying the WAter vapour Lidar Experiment in Space (WALES), which is a water vapour differential absorption lidar. WALES retrieved ice optical thickness of cirrus clouds during a flight over Germany on the 18 October 2008. The main advantage is that a High Spectral Resolution Lidar was used The collected data were collocated and compared with different SEVIRI based cloud retrievals.

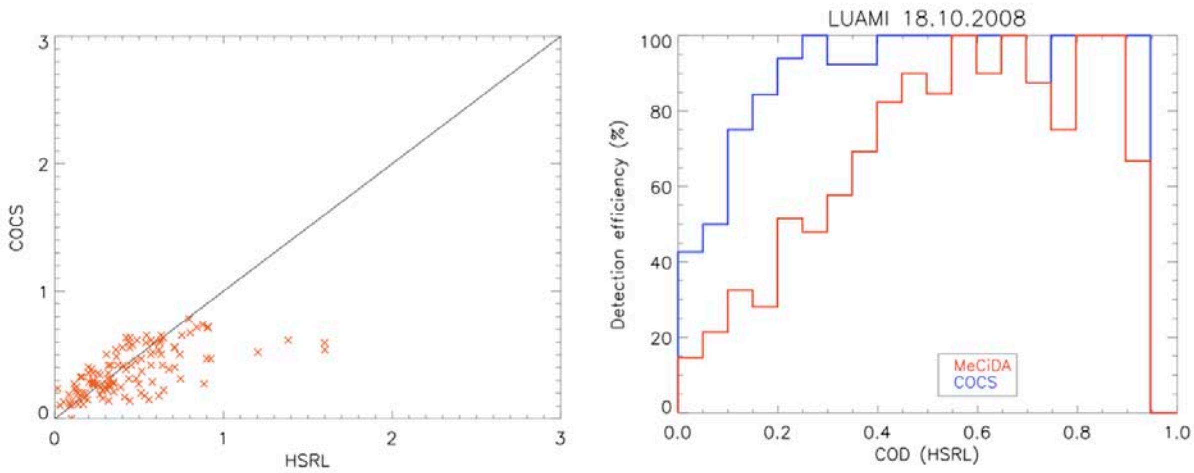

Figure 4: Validation of IOT (left) with retrieved HSRL data of the WALES instrument during the LUAMI campaign on the 18 October 2008.
Detection efficency of COCS and APICS on the right, courtesy of A. Ostler.

Figure 4 shows the intercomparisons of COCS and the WALES system. COCS shows high correlations with those measurements with a very low standard deviation of IOT=0.17 on the left, while the detection efficiency (right) is close to 100% for IOT ≥ 0.2 .
The Meteosat Cirrus Detection Algorithm (MeCiDA, [Krebs et al, 2007]) shows a lower detection efficiency for thin cirrus, but is able to detect 100% of the cirrus clouds with a optical thickness greater than 0.5 .

COCS – Selected Applications

Figure 5 shows the results of a single time slot of COCS ice optical thickness (left) and top altitude (right). At 00:00 UTC on the 05 April 2009 several atmospheric features are present in the area covered by SEVIRI.

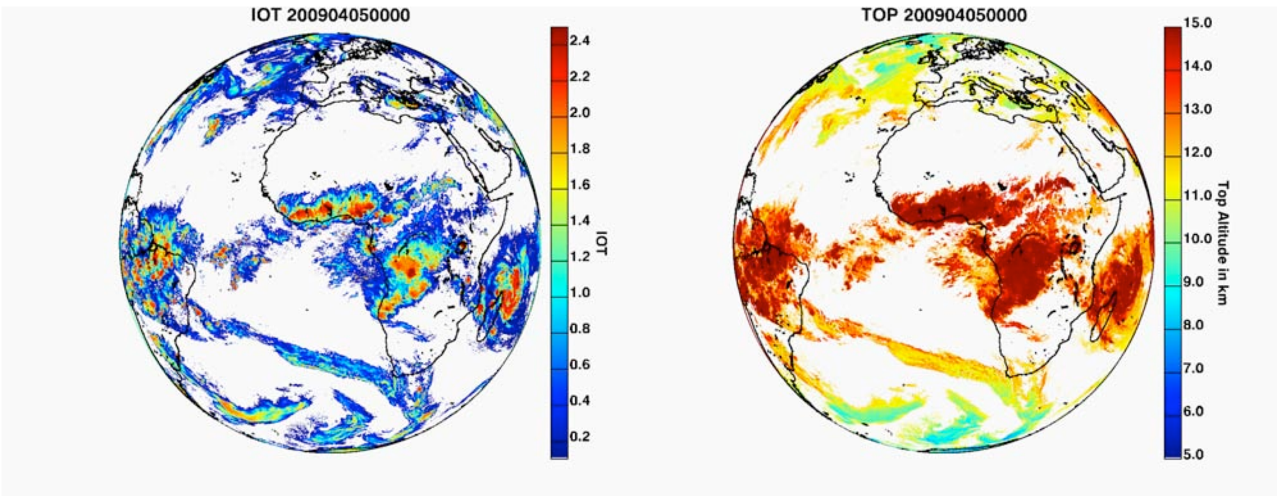

Figure 5: COCS result for 05 April 2009 at 00:00 UTC. Ice optical thickness on the left, Top altitude of cirrus clouds in km on the right.

Beside the frontal zones in high and low latitudes, some convective features are detected over Central Africa and South America. The remains of a tropical cyclone are located over Madagascar. On the one hand COCS covers the high variety of IOT on the whole disc with a range of 0.1 ≤ IOT ≤ 2.5, on the other hand the detected TOP shows the inhomogenety within different latitudes.

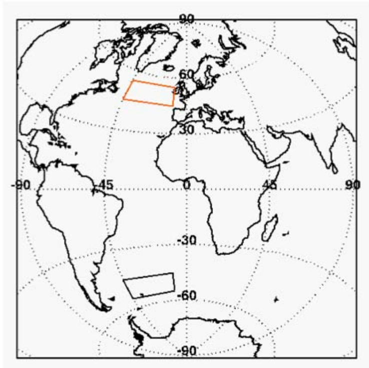

Figure 6: Definition of North Atlantic (orange, NAR) and South Atlantic (black, SAR) Region

As mentioned in the introduction COCS is now able to provide diurnal cycles of cirrus clouds due to the high temporal resolution of SEVIRI based on the 15 min full disc measurements shown in Figure 5. Diurnal cycles can provide information on the daily and seasonal changes in atmospheric properties as well as on different processes influencing formation and decay of clouds.

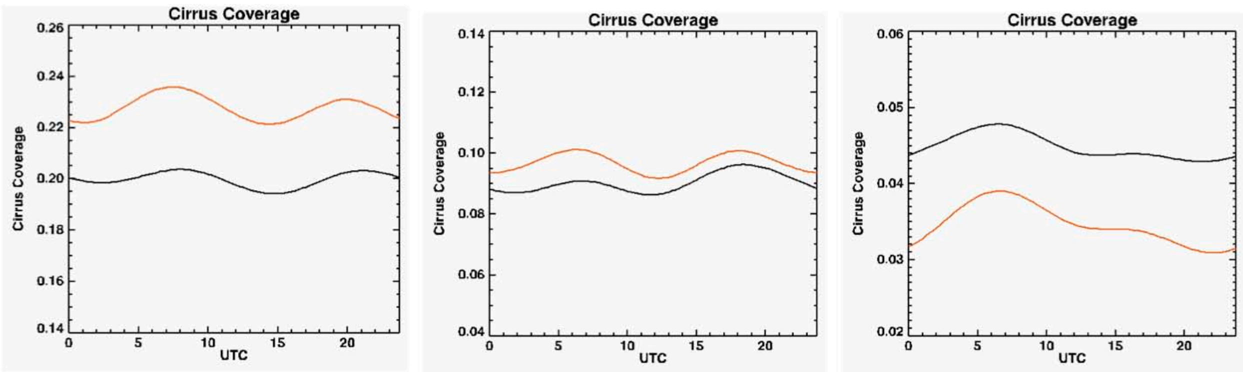

Figure 7: Dirunal cirrus coverage of different regimes of ice optical thickness for NAR (orange) and SAR (black), starting with 0.1 ≤ IOT < 0.5, 0.5 ≤ IOT < 1.0, and 1.0 ≤ IOT ≤ 2.5 (from left to right) for the year 2008.

In this study we analyze single areas on the SEVIRI disc for the year 2008. Since the German Aerospace Center is interested in the cirrus formation and decay due to airtraffic,
K. Graf et al [2009] started with the analysis of the North Atlantic Region (NAR, shown in Figure 6, where the transcontinental airtraffic from Europe to the US and reverse is travelling through. This airtraffic takes place in a kind of double wave. In the morning planes from Europe to the US pass the NAR, while planes from the US to Europe pass it in the afternoon.
After analysis of the South Atlantic Region covering the same area mirrored to the southern hemisphere, where no airtraffic „disturbs“ natural cirrus formation, we can observe a shift of cirrus cloud cover to earlier daily minima and maxima in the NAR, which might be caused by airtraffic (Figure 7).

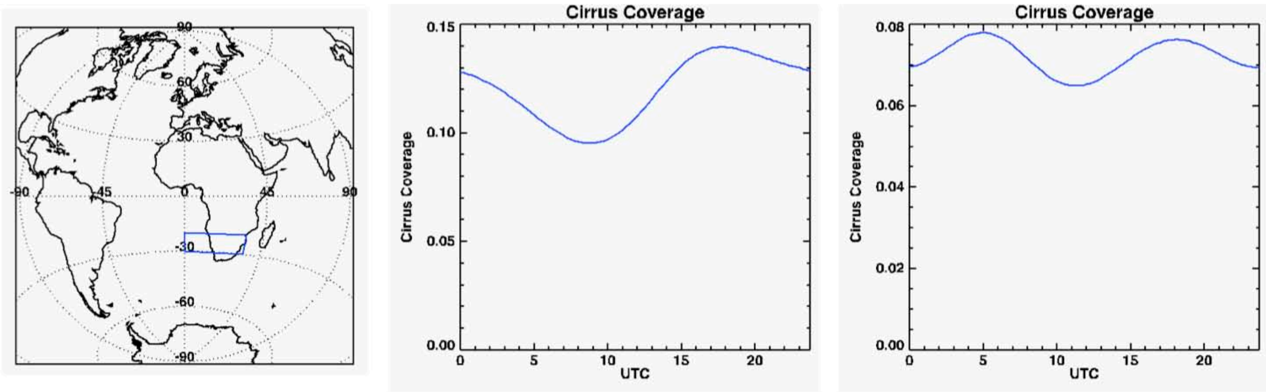

Figure 8: Left: SAC definition. Center: Diurnal cirrus coverage for the year 2008 over the SAC region. Right: Diurnal cirrus coverage for April 2008.

Also differences in the daily cycle of ice optical thickness can be identified as we take a closer look to the different regimes of ice optical thickness, shown in Figure 7. In the NAR more cirrus clouds with low IOT are observed while in the SAR thicker cirrus is detected. This effect may also be caused by airtraffic.
Since we are lacking an explanation of microphysical processes behind this "double wave" phenomenon in the SAR, we investigate further regions to find out, whether there is a similar effect or not.

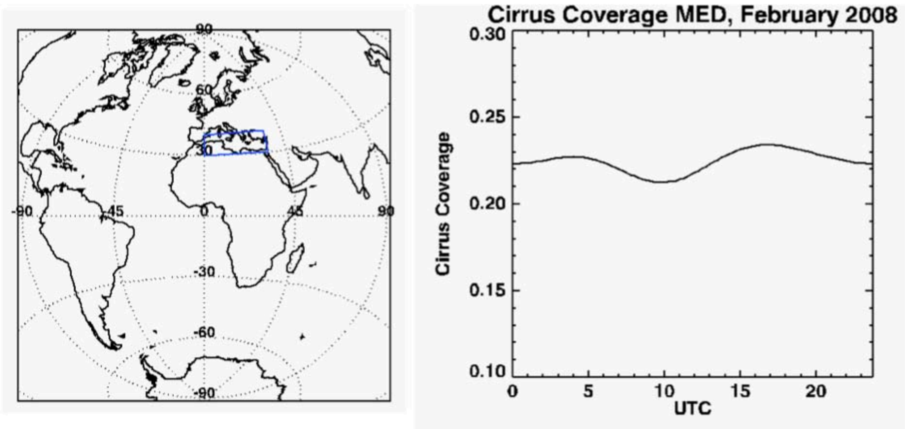

Figure 9: Left: MED definition. Right: Diurnal cirrus coverage in the MED, April 2008.

The first additionally selected region is the South African Continental region (SAC), shown in Figure 8 (left), covering equally land and water. Figure 8 (center) shows that in 2008 the diurnal cycle of cirrus coverage is dominated by convective cloud formation in the afternoon. But in southern hemispheric autumn, when convection is less dominant like in February 2008 , the double oscillation takes place again (Figure 8, right).
The second region is the Mediterranean region (MED, Figure 9, left), where the analysis is limited to a month with less convective cloud formation, February 2008. Again the double oscillation is obvious in the morning and the afternoon (Figure 9, right).

Finally we want to give an additional example of application of COCS. Since COCS is sensitive to thin cirrus combined with the good spatial and the very high temporal resolution of MSG-8 in Rapid Scan Mode (the northern hemisphere is covered every 5 minutes) it is now possible to retrieve ice optical thicknesses of contrail cirri detected and tracked with the Automatic Contrail Tracking Algorithm (ACTA, [M. Vazquez-Navarro, 2010]).

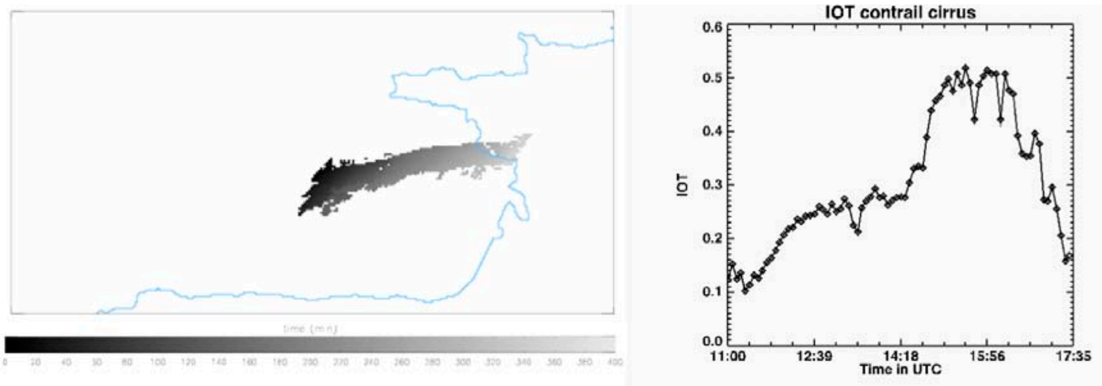

Figure 10: Left: Shape of one single contrail cirrus on 05 April 2009 over the Gulf of Biskay tracked with ACTA [M. Vazquez-Navarro, 2010]. Right: Mean IOT of this contrail cirrus retrieved with COCS.

Figure 10 (right) shows the mean IOT of one single contrail cirrus, which was tracked with ACTA on 05 April 2009 from 11:00 until 17:35 UTC. The first time steps show low ice optical thicknesses, while it raises strongly at around 14:45 UTC when the contrail cirrus merges with other contrail cirri and natural cirrus. On the left the shape is plotted during its lifecycle.

Conclusions and Outlook

The Cirrus Optical properties derived from CALIOP and SEVIRI algorithm (COCS) retrieves the ice optical thickness (IOT) and the top altitude of cirrus clouds (TOP) with very good precision. With its high spatial and temporal resolution this tool can on the one hand support the understanding of decay and formation of cirrus clouds on the other hand it even provides information of fine cirrus structures, such as contrail cirrus.
COCS is sensitive to cirrus clouds with an ice optical thickness up to 2.5 where it gets saturated. Until now we processed almost 5 years of data (2006 - 2010).
Preliminary analysis of this data shows a double oscillation of diurnal cirrus coverage in different regions of the SEVIRI-disc. This oscillation will be taken under closer investigation since the theory behind this oscillation is still incomplete.

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