Ice optical thickness retrieval using SEVIRI-1/2/3 aboard the Meteosat 8-10 satellites: towards a cirrus life cycle analysis

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ABSTRACT: COCS is a neural network trained with coincident SEVIRI (Spinning Enhanced Visible and Infrared Imager) and CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) measurements in order to retrieve the ice optical thickness (IOT) and the ice cloud top altitude using the thermal channels of SEVIRI. In this paper the instrument dependence for the IOT retrieval of COCS is investigated using the three SEVIRI instruments aboard the operational Meteosat Second Generation (MSG) satellites as a first step towards the analysis of the cirrus life cycle. From a combination of qualitative and quantitative analysis using COCS IOT together with SEVIRI false color RGB composites and IOT derived from CALIOP L2 data it is concluded that COCS has a clear instrument dependence and tends to overestimate the amount of thin ice clouds (IOT≲0.30) in the tropics when applied to SEVIRI-2/3. COCS seems to be more accurate using SEVIRI-1 data and thus it is further concluded that SEVIRI-1 should be prioritized for natural and contrail cirrus analysis in the tropics unless this feature is alleviated with a re-training of COCS.

1 INTRODUCTION

The "Cirrus Optical properties derived from CALIOP and SEVIRI during day and night" (COCS, Kox et al, 2014) algorithm is a neural network that has been trained with coincident measurements by SEVIRI-1/2 and CALIOP. The SEVIRI instruments (Schmetz et al, 2002) operate in geostationary orbits with 7 thermal and 3 solar channels together with one mixed solar/thermal channel. Since 2004 the instruments have been launched aboard MSG four times (October 2015). CALIOP was launched in 2006 and is a space-borne polarized LIDAR operating in a polar orbit with a vertical resolution of up to 30m (Winker et al, 2009). With COCS the main advantages of the two instruments have been combined i.e. the high temporal resolution and spatial coverage of SEVIRI and the high vertical resolution of CALIOP. COCS takes seven SEVIRI brightness temperatures and brightness temperature differences together with latitude, viewing zenith angle and a land-sea mask as input and provides the IOT and the ice cloud top altitude as output. Since COCS is independent of solar channels and thus solar radiation it can operate during both day and night. To maintain sufficiently high ice cloud detection efficiency together with a low false alarm rate, COCS IOT values lower than 0.1 are considered too inaccurate and are set to zero (Kox et al, 2014).

As a first step towards a cirrus life cycle analysis using COCS in combination with other algorithms, the instrument dependence of the COCS IOT is presented in this paper. As explained above, COCS is trained with data from SEVIRI-1/2, but even though SEVIRI-1/2/3 have the same design and specifications they cannot be identical and COCS can therefore not be assumed to work identically when applied to data from the three respective instruments.

This paper is divided into four sections. Following the introduction, the COCS instrument dependence analysis and the conclusions are presented in section 2 and 3 respectively. Finally an outlook for the next steps towards the cirrus life cycle analysis is presented in section 4.

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2 THE INSTRUMENT DEPENDENCE OF COCS

2.1 *Qualitative comparison between COCS IOT and SEVIRI false color RGB composites*

As a first step the COCS IOT for three MSG SEVIRI scenes were analyzed (2006-05-01, 2010-05-01 and 2015-05-01 at 13:00 UTC), representing the currently operational SEVIRI-1, SEVIRI-2 and SEVIRI-3 instruments respectively. For a qualitative analysis of the COCS ice cloud detection efficiency and false alarm rate the IOT for the three SEVIRI scenes were compared to corresponding false color RGB composites derived using the SEVIRI channels 1, 2 and 9 (0.6, 0.8 and 10.8µm). The COCS IOT for the three SEVIRI scenes together with the corresponding false color RGB composites can be seen in Fig. 1. From the false color RGBs one gets a good 2D overview of the atmosphere and clouds can easily be separated from clear skies. Furthermore, colder ice clouds can be distinguished from the warmer water clouds, as they appear as white or bluish while the warmer water clouds appear as yellowish. Since the three scenes are from three different years we cannot make a quantitative comparison of the COCS IOT for the three SEVIRI instruments, but we can see that for all three instruments COCS succeeds in identifying the evident ice clouds in the respective RGBs. The frontal systems in the mid-latitudes and the convective clouds along the inter-tropical convergence zone are successfully captured by COCS as well as the cloud free regions at the subsidence zones around the horse latitudes.

For the SEVIRI-2/3 scenes COCS retrieves significantly more thin ice clouds (Fig. 1 center and bottom right) compared to the SEVIRI-1 scene (Fig. 1 top right), especially in the tropics. The IOT-RGB comparison apparently reinforces this impression, that the amount of thin ice clouds in the tropics is overestimated by COCS when applied to the SEVIRI-2/3 data. However it is unclear whether/when thin ice clouds with optical thicknesses in the range 0.0-0.3 should be visible in a false color composite.

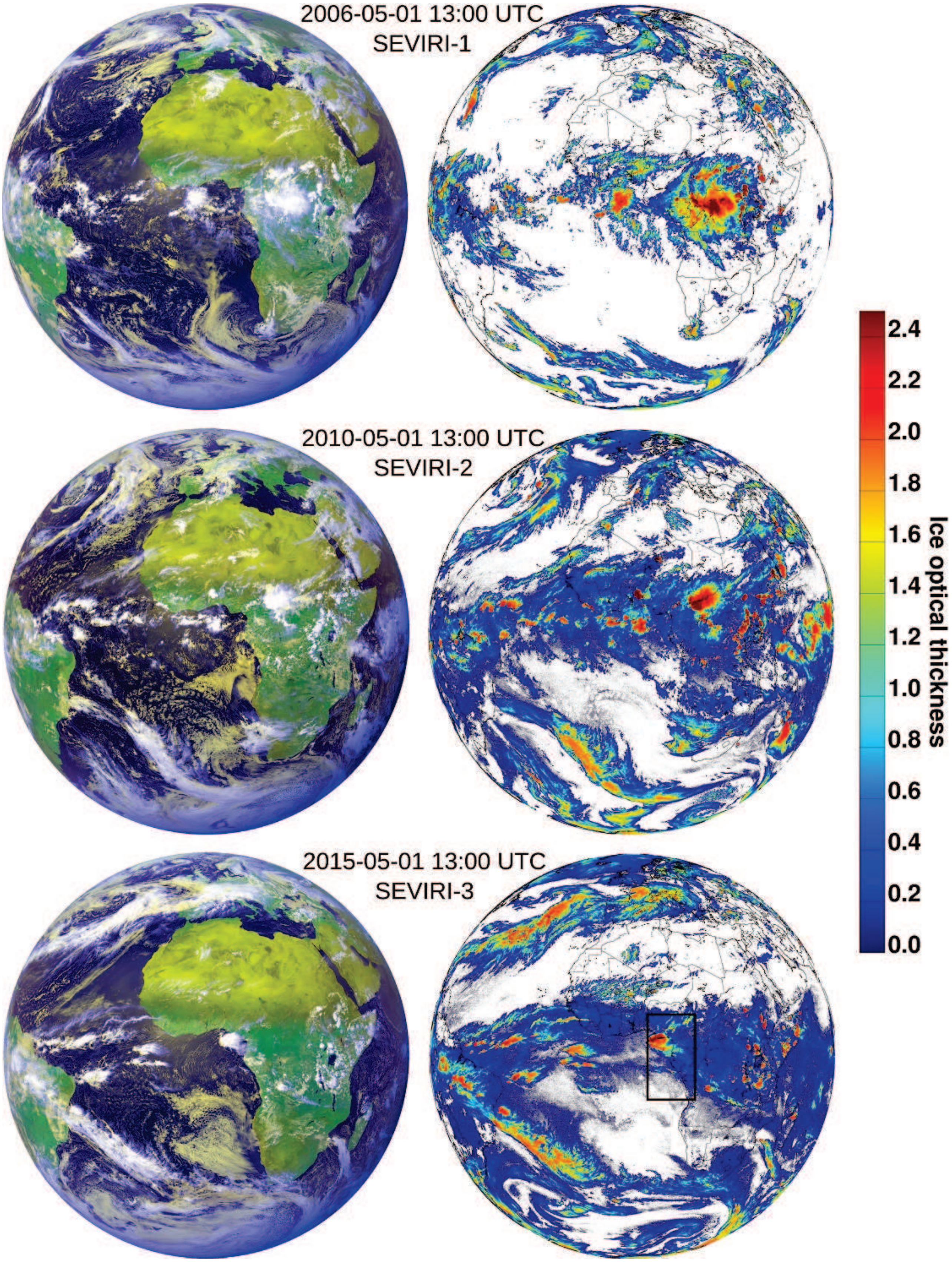

Figure 1: SEVIRI false color RGB composites (left column) and ice optical thickness retrieved by COCS (right column) using SEVIRI-1 (top), SEVIRI-2 (center) and SEVIRI-3 (bottom). Ice clouds are recognized as white or bluish in the false color composites, whereas liquid water clouds are recognized as yellowish. The black rectangle in the bottom right figure shows the region studied in more detail in section 2.2

2.2 *Quantitative comparison between COCS and CALIOP IOT*

To acquire more information on whether COCS in fact overestimates the amount of thin ice clouds in the tropics using the more recent SEVIRI-2/3 instruments, a more quantitative point-by-point comparison between the COCS IOT and IOT derived from the CALIOP L2 cloud layer data on a 5km horizontal grid (CAL_LID_L2_05kmCLay-Prov-V3-30) was made. CALIOP IOT from 10°S to 10°N (12.3°E to 8.5°E) was extracted and matched spatially and temporally to the COCS IOT from the SEVIRI-3 scene (at 2015-05-01 13:00 UTC). The result can be seen in Fig. 2.

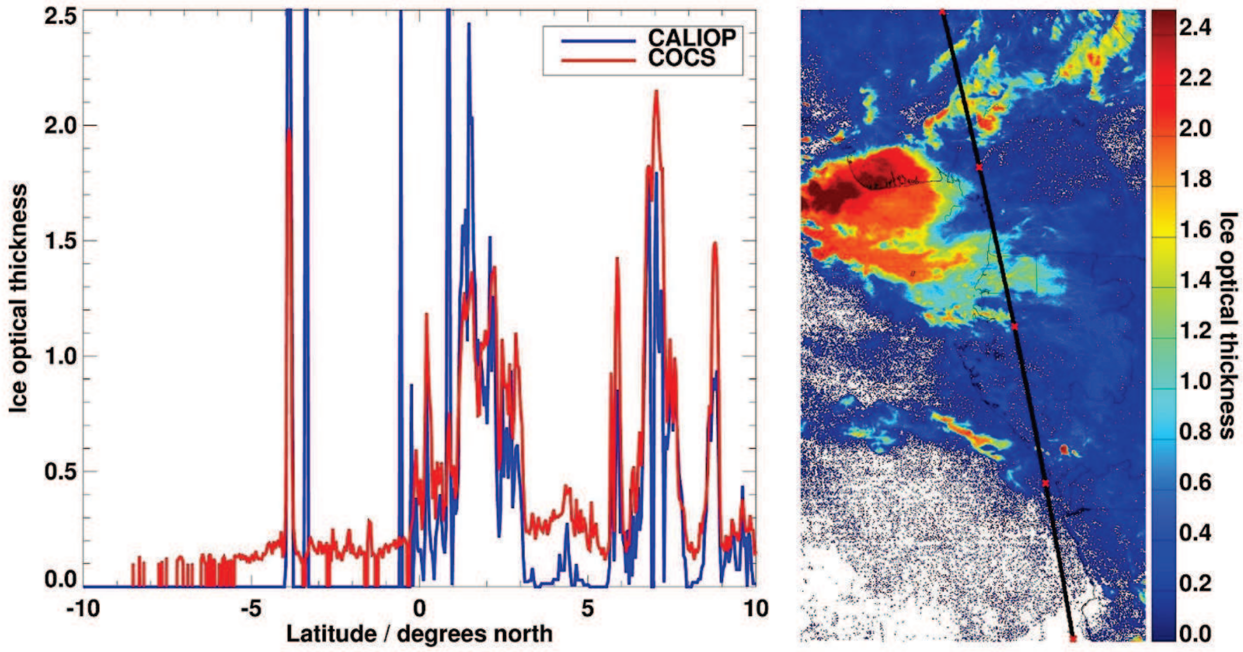

Figure 2: Left: point-by-point comparison between COCS and CALIOP IOT along the CALIOP track in the tropics (from 10°S to 10°N). Right: The CALIOP track on top of the COCS IOT for the region of comparison. Latitudes from 10°S to 10°N are marked with red crosses on the CALIOP track with a 5 degree interval for an easier comparison with the left figure.

From the Fig. 2 it is clear that COCS has high detection efficiency and the respective peaks in the COCS and CALIOP IOT are spatially very well aligned. However, the issue discussed in section 2.1 remains, namely that COCS has a high false alarm rate in the tropics. Where CALIOP detects IOT values less than 0.1 (i.e. no ice cloud according to COCS due to its lower detection threshold at 0.1), COCS generally obtains IOT values ranging from 0.1 to 0.3, resulting in a high false alarm rate of COCS. This pattern can clearly be seen at latitudes< -4°N, -3.5°N<latitudes<-0.5°N and 3°N<latitudes<5.5°N.

3 CONCLUSION

The instrument dependence of the neural network based algorithm COCS is investigated using data from SEVIRI-1/2/3. A qualitative comparison between the IOT derived by COCS and corresponding SEVIRI false color RGB composites was made together with a more quantitative comparison between the COCS IOT and IOT derived from CALIOP L2 cloud layer data. It is concluded that COCS has a clear instrument dependence and tends to overestimate the amount of thin ice clouds (IOT≲0.30) in the tropical regions when it is applied to data from SEVIRI-2/3 compared to SEVIRI-1 data. Unless this feature is alleviated with a re-training of COCS it is recommended to prioritize SEVIRI-1 data for natural and contrail cirrus analysis in the tropics using COCS.

It is also concluded that for the training of a neural network like COCS it would be favorable to separate data from the respective SEVIRI instruments and possibly also regions with large climatological differences like the tropics and the mid-latitudes.

4 OUTLOOK

The next steps towards the analysis of the cirrus life cycle are (1) to further analyze the performance of COCS for the three SEVIRI instruments for a better and more complete understanding of the results presented in this paper. (2) To perform a validation and characterization of COCS using simulated SEVIRI brightness temperatures or CALIOP data to understand how COCS performs for different vertical cloud structures; e.g. one layer ice cloud, multiple vertically separated layers of ice clouds, ice clouds above liquid water clouds etc. (3) To develop a sophisticated cirrus tracking algorithm that can work in synergy with COCS and other algorithms in order to monitor the temporal evolution of optical, macro- and microphysical properties of ice clouds.

With respect to (2) above, Fig. 3 shows a comparison between measured and simulated SEVIRI brightness temperatures at 9.7μm (left) and temperature differences between 6.2 and 7.3μm (right). The simulated data have been calculated with the radiative transfer model libRadtran (Mayer and Kylling, 2005) using meteorological data from ECMWF (European Centre for Medium-Range Weather Forecasts) together with spectral surface emissivities from the Moderate Resolution Imaging Spectroradiometer (MODIS) (Seemann et al, 2008). With a generally high correlation between measured and simulated brightness temperatures and temperature differences the simulated data constitutes a potentially good data set for the validation and characterization of COCS. For temperature differences (between 6.2 and 7.3μm) greater than approximately -15°C the correlation is reduced and this feature should be investigated before a validation and characterization of COCS using the simulated data set is made.

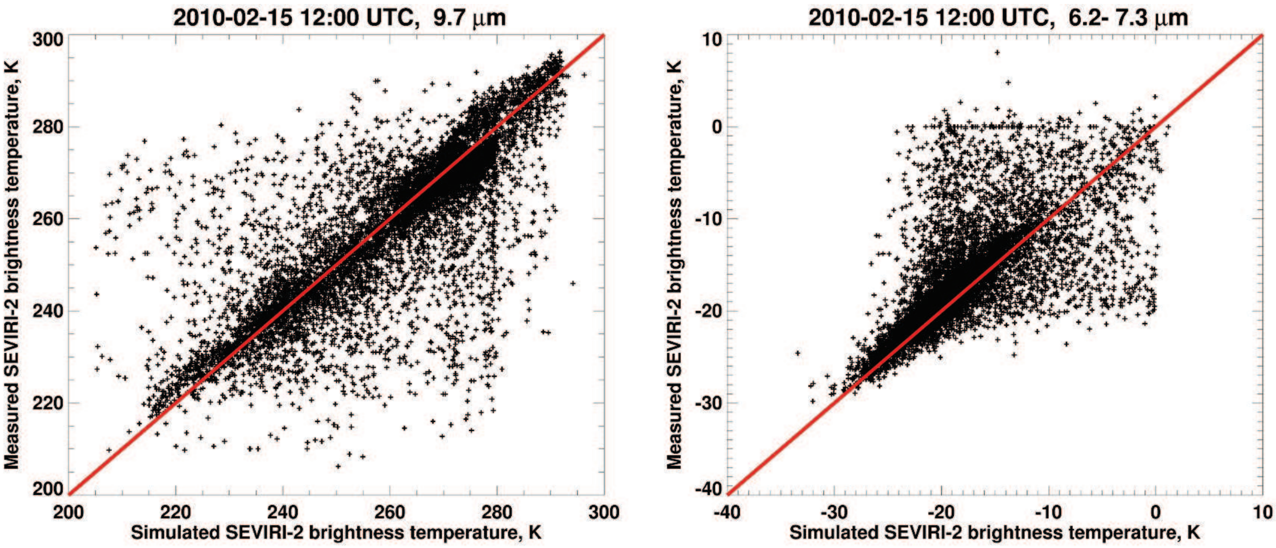

Figure 3: Simulated SEVIRI-2 brightness temperatures ($BT_{9.7\mu m}$) and temperature differences ($BT_{6.2\mu m}$-$BT_{7.3\mu m}$) versus the corresponding measured SEVIRI-2 brightness temperatures and temperature differences.

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