OBSERVING CIRRUS FORMATION AND DECAY WITH METEOSAT

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Abstract

Cirrus clouds have a substantial impact on net radiation and therefore also on climate, but the physical processes involved in cirrus formation and decay are not very well represented in climate and weather prediction models. In-situ formation of natural cirrus clouds is initiated when cooling moist air parcels reach a substantial super-saturation with respect to ice. This happens either due to dynamic lifting of the air or due to radiative cooling. But once ice crystals are formed, they grow until the ambient air becomes sub-saturated either by subsidence of the whole air-mass or sedimentation of the particles into drier air. Thus the pure diagnostic description of clouds, as it is used in current climate and weather prediction models has to be tuned to match observations at least until a prognostic description of cirrus clouds will be introduced into these models.

The decay of cirrus clouds is a process with a typical timescale of hours. Therefore geostationary satellites with their high temporal resolution are an ideal platform for cirrus observations. The data from these satellites offer the possibility to observe the life cycle either by tracking cirrus clouds or by observation of the typical daily and seasonal variation of cirrus coverage. In particular the infrared channels of the METEOSAT satellites, which are independent from day-light and not affected by the different scattering properties of the various ice particle habits are suitable for such observations.

In this article we analyse the daily variation of cirrus coverage in the Southern Atlantic and Indian Ocean region, as this wide area is not affected by deep convection, which dominates the daily variation of cirrus coverage over land.

MOTIVATION:

In Waliser, D. et al. (2009) we find an extensive discussion of the importance of cloud ice in weather and climate modelling. In comparison to other variables like precipitation, precipitable water or total cloud fraction, the climate models used for the IPCC 4th Assessment Report show large differences in global mean ice water path. This is an indicator for a poor and inconsistent data basis, as the upper tropospheric ice clouds are still used for the tuning of the models. Process based models of ice clouds as described by Burkhardt et al. (2009) for contrail cirrus are still not widely used in climate or weather models. In these models cloud properties are diagnosed from other model parameters. Waliser et al. conclude, that 'much of the challenge has been associated with a lack of high-quality, global observations of ice clouds and related quantities.' The daily variation of ice clouds over areas not affected by convection over land might help to set up process based models of the cirrus life cycle as the impact of radiation on cirrus formation and decay is separated from the dynamics of weather.

A further motivation to look at the daily variation of cirrus coverage results from the observation of double peaked cirrus coverage over the northern Atlantic ocean (Graf et al., 2009), which is directly related to the impact of air traffic. In order to use these measurements to derive the anthropogenic changes in cirrus coverage and properties first the natural variation of cirrus has to be known.

An ideal area for such observations within the disc observed by METEOSAT in its normal position is found in the Southern Atlantic and Indian Ocean south of Africa between 45°S and 60°S stretching from 45°W to 45°E as indicated in Fig. 3.

DAY- AND NIGHTTIME CIRRUS DETECTION (MECIDA):

The cirrus detection algorithm for the Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) aboard the geostationary Meteosat Second Generation (MSG), MeCiDA (Krebs et al., 2007) is used to derive the cirrus coverage for our study area. The algorithm uses the seven infrared channels of SEVIRI and thus provides a consistent scheme for cirrus detection at day and night. MeCiDA combines morphological and multi-spectral threshold tests and detects optically thick and thin ice clouds. The thresholds were determined by a comprehensive theoretical study using radiative transfer simulations for various atmospheric situations as well as by manually evaluating actual satellite observations. The cirrus detection originally has been optimized for the North Atlantic and European regions. During this study we realized that one of the 6 tests is affected strongly by seasonal variations of ozone. Therefore we used here only the tests 1-5 described in (Krebs et al., 2007). Meanwhile a new, enhanced version of MeCiDA is available and will be published within 2010.

In contrast to other definitions of cirrus used mainly by ground based or LIDAR observations we interpret cirrus as a synonym for ‘ice clouds’, i.e. clouds with optical properties dominated by the ice phase. Therefore also thick Cumulonimbus tops and Cirrostratus layers are included.

The MeCiDA cirrus detection compares well to active measurements by the CALIOP lidar (Winker et al., 2008) flown on the CALIPSO satellite within the so called A-Train. In Fig 1 we show the MeCiDA detection efficiency as a function of the ice optical depth from the 5 km CALIOP cloud layer product. As expected, the detection efficiency increases with the optical depth and reaches values close to unity for optical depths > 1. All CALIPSO day- and night-time overpasses from Nov 1st to Nov 17th 2006 are collocated to the parallax corrected METEOSAT SEVIRI data. The 50% detection efficiency is reached for ice optical depths of 0.25. A perfect match of the detection is not possible due to the sub-pixel variability of cirrus clouds. The total footprint of the CALIOP measurements (apr. 1 km^2 resulting from 10 single shots of 300 m diameter in the 5 km product) is much smaller than the typical SEVIRI IR pixel footprint of apr. 20 km^2. Even if CALIOP does not detect any cirrus MeCiDA finds in 13% of the cases a cirrus cloud, which is not necessarily a ‘false alarm’.

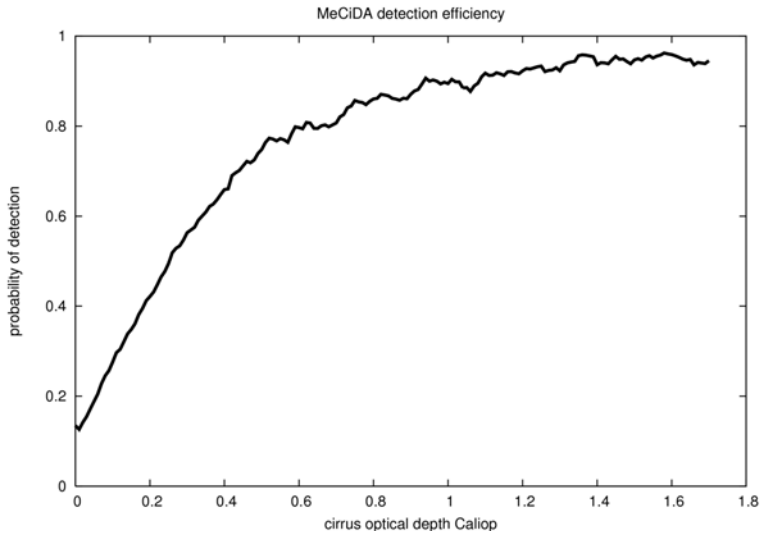

Figure 1: **Performance of the MeCiDA cirrus detection: probability of detection as a function of optical depth from CALIOP day and night-time measurements**

The ground based lidar measurements by Immler et al.(2008) and the CALIOP measurements show a similar distribution of optical depths of cirrus clouds. Ground based lidar measurements are biased to fair weather situations without low- and mid-level clouds. Thus it is unlikely to observe in situ cirrus formation, which leads to higher optical depths (Spichtinger et al., 2006, Kärcher et al. 2009). On the other hand CALIOP detection of cirrus is limited for low optical depths. The shift of the distribution in Fig. 2 to lower optical depths in the ground based observations is in accordance to the basic idea that the long tail to low optical depths results from aging of sedimenting cirrus.

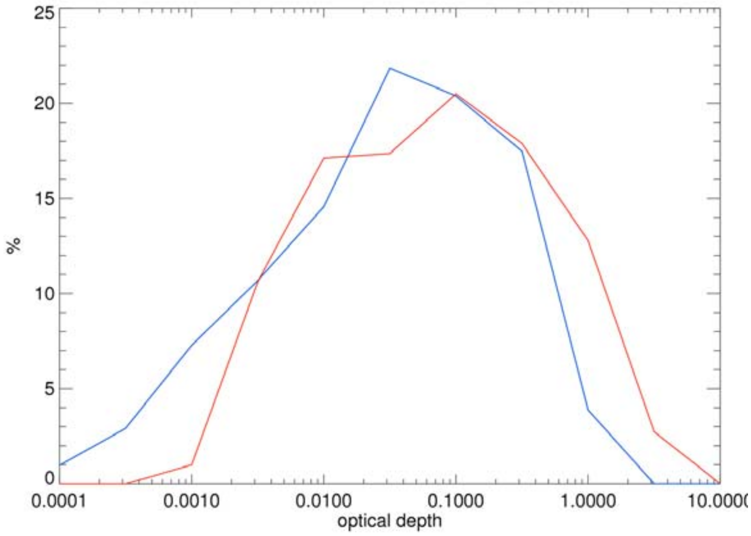

Figure 2: **Comparison of the distribution of optical depths measured from ground in blue (derived from Immler et al. 2008) and the CALIOP measurements used for Fig. 1 in red.**

Using the distribution of optical depth τ derived from CALIOP measurements and the detection efficiency in Fig. 1 we can estimate that MeCiDA detects 35% of all and 55% of the visible cirrus defined by $\tau > 0.02$. The impact of cirrus on radiation scales with $1-\exp(-\tau)$. With these weights, 77% of the impact of cirrus on radiation is expected from the cirrus clouds detected by MeCiDA.

We processed all METEOSAT SEVIRI data in full resolution for 48 months starting with February 2004, when MSG1 became operational. MeCiDA results in a binary decision on cirrus coverage for each pixel. These 140000 masks are sampled into a 1 month x 1° longitude x 1° latitude x 1 hour grid array with 48x90x15x24 values of cirrus coverage for further evaluation. As our main concern is the daily variation, we converted the UTC times of the original data into longitude dependent local times in the sampling process. Fig. 3 indicates our region of interest in the southern part of the visible disc.

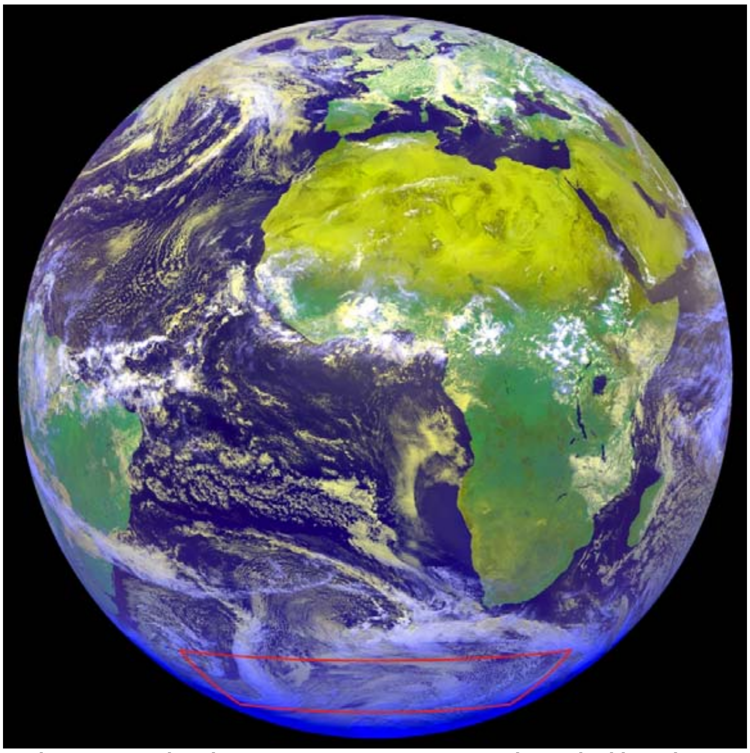

Figure3: **MSG Full disc colour composite, the area 45°S-60°S, 45°W-45°E is marked in red**

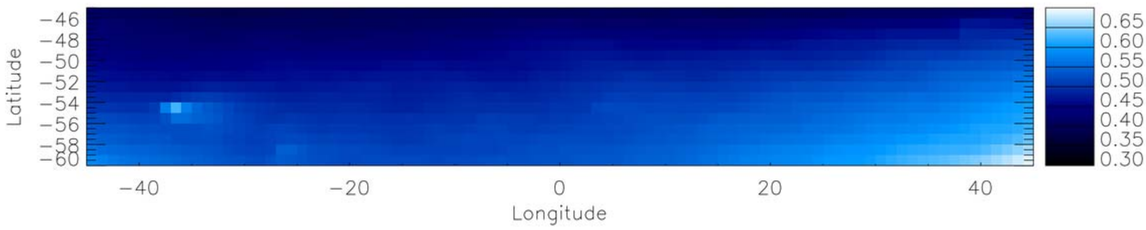

Figure 4: Mean cirrus coverage at **45°S-60°S, 45°W-45°E, 4 years from Feb. 2004-Jan 2008. The inhomogeneity in the left part indicates the position of South Georgia Island at 54°S, 37°W, reaching with Mount Paget an altitude of 2935m. We assume, that this mainly glaciated island initiates orographic cirrus formation.**

The N-S gradient of the cirrus coverage distribution is the dominant feature in Fig 4. Higher cirrus coverage in the SW and SE corners of our region might result from a higher detection efficiency due to the large satellite viewing angle close to the edge of the visible disc. Higher values at 54°S, 37°W show the position of South Georgia Island, the only island within this area reaching altitudes higher then 1000m. Placed in the ‘thundering 50ies’, this mainly glaciated island initiates sometimes orographic cirrus formation which enhances the mean coverage up to several hundred km downstream of the island.

Within the MeCiDA derived cirrus coverage we see a strong seasonal cycle with values of 42% in January and 57% in August and September (Fig.5).

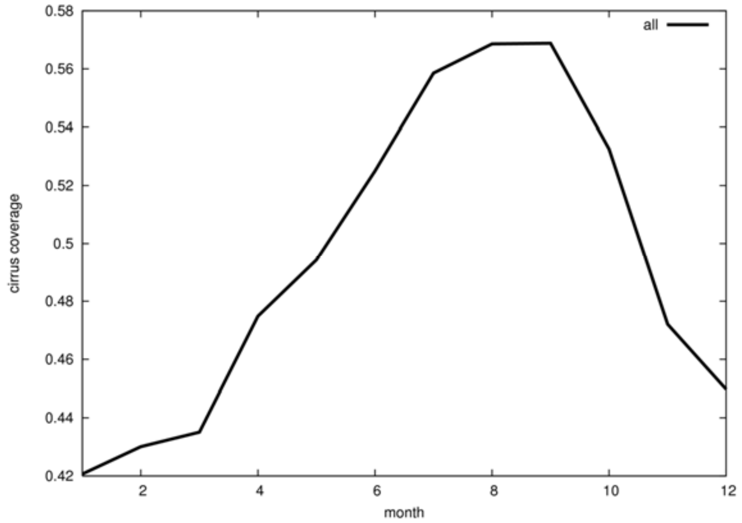

Figure5: **Seasonal variation of cirrus coverage *at* 45°S-60°S, 45°W-45°E, derived from 4 years starting with Feb. 2004**

DAILY VARIATION OF CIRRUS COVERAGE:

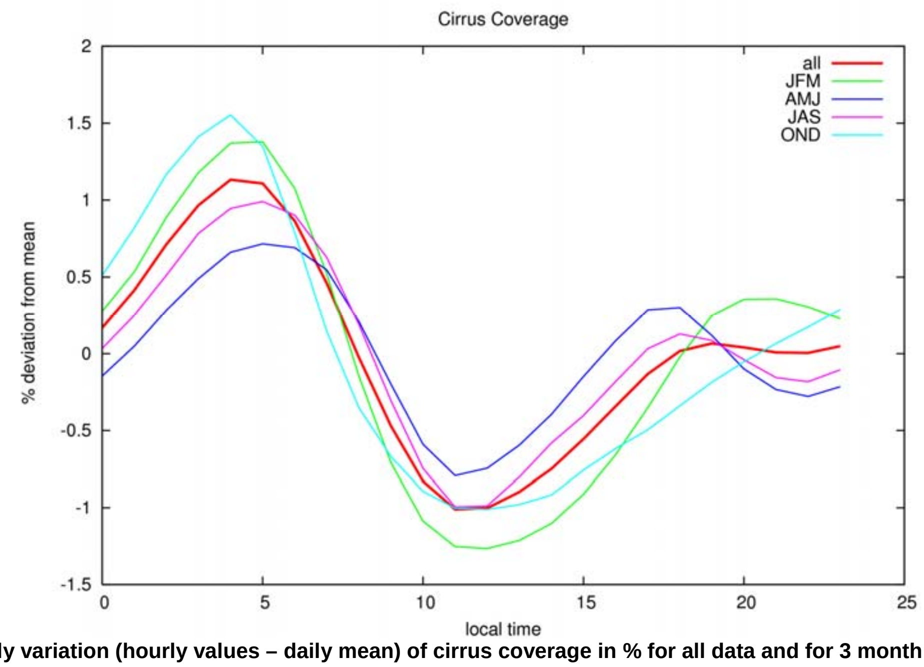

Figure6 : **Daily variation (hourly values – daily mean) of cirrus coverage in % for all data and for 3 month periods summer (JFM), autumn (AMJ), winter (JAS), and spring (OND) in the southern hemisphere.**

The daily variation if MeCiDA derived cirrus coverage in the southern mid latitudes over ocean (Fig. 6) shows a maximum at local sunrise and a minimum at noon. The increase in coverage during afternoon and night is interrupted by a secondary maximum at sunset except for the late spring months October, November, and December. The signal is very robust and shows up already in monthly means because of the large longitudinal extension of the data set, which integrates over several synoptic features. This daily cycle does not show the apr. 8% higher day-time cirrus coverage, which is derived from CALIOP measurements for this area (Nataryan, H., 2009). For the interpretation of this signal it has to be kept in mind that a change in detected cirrus coverage by any measuring device can result not only from a change in the area covered by cirrus, but also by a change in the optical depth of already existing cirrus which has an impact on the probability of detection (see Fig.1). Therefore we cannot exclude, that the higher day-time cirrus coverage at noon seen by CALIOP results from cirrus with low optical depth. We still have no model, which can explain the details of the daily variation, but this analysis suggests that the direct solar heating of the cirrus clouds plays an important role in cirrus decay.

CONCLUSIONS:

The infrared channels of the METEOSAT satellites, which are independent from day-light and not strongly affected by the different scattering properties of the various ice particle habits are suitable for the observation of those cirrus properties, which are directly affected by solar radiation. With MeCiDA we have an excellent tool to derive the coverage by those cirrus clouds, which have a strong impact on net radiation. Beyond MeCiDA we are developing methods to derive the visible optical depth of ice clouds from measurements in the METEOSAT SEVIRI infrared channels.

Within the disc visible from the geostationary METEOSAT satellites the ocean area south of Africa spanning from 45°W to 45°E is an ideal area for such studies, as the daily cycle is not affected by deep convection initiated over land surfaces. The daily variation of cirrus clouds has an amplitude of apr. 1% with the maximum at sunrise, the minimum at noon. Because this feature is closely related to solar radiation we expect, that it influences cirrus coverage on the whole globe, but is often buried under the strong influence of deep convection.

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