Evaluation of the diurnal cycle of model predicted cloud properties using MSG-SEVIRI observations

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Abstract. The evaluation of the diurnal cycle of cloud properties as predicted by climate models receives relatively little attention, mostly due to the lack of observational data. The Spinning Enhanced Visible and Infrared Imager (SEVIRI) onboard the geostationary METEOSAT-8 satellite is the first instrument able to provide accurate information on diurnal cycles during daylight hours of cloud properties over land and ocean surfaces. This paper evaluates the diurnal cycle of Cloud Amount (CA), Cloud Phase (CPH) and Condensed Water Path (CWP) as predicted by the Regional Atmospheric Climate Model (RACMO), using corresponding SEVIRI retrievals. The study is done for Europe using hourly cloud properties retrievals from SEVIRI during the summer of 2004.

Keywords: SEVIRI, Climate Models, diurnal cycle, Cloud Amount, Condensed Water Path.
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INTRODUCTION

Accurate information on the diurnal cycles of cloud properties over land and ocean surfaces would provide a key test of many aspects of the physical parameterizations in weather and climate prediction models, such as the representation of convection, turbulence and cloud processes. Various methods have been developed to retrieve spatial and temporal distributions of cloud properties from satellite measurements. Passive imagers, such as SEVIRI and MODIS (Moderate Resolution Imaging Spectroradiometer), are one way to retrieve cloud properties over land and ocean surfaces from visible and near-infrared reflectances and infrared radiances. The methods to retrieve CPH use either visible and near-infrared reflectances [1] or infrared radiances [2, 3], while the methods to retrieve CWP from passive images are solely based on visible and near-infrared reflectances (see e.g. [4, 5, 6])

In this paper we evaluate the diurnal cycles during daytime CA, CPH and CWP from the Regional Atmospheric Climate Model (RACMO) using corresponding cycles derived from SEVIRI. The study area covers large parts of Europe comprising land and ocean surfaces. The cloud properties are retrieved with the Cloud Physical Properties algorithm (CPP) that has been developed within the Climate Monitoring Satellite Application Facility (CM-SAF) of EUMETSAT. The evaluation of RACMO is carried out by comparing the mean seasonal values of CA, CPH and CWP against SEVIRI observations. The diurnal cycles of these cloud properties are evaluated in greater detail for four subdomains that are located in different climate zones. Finally, results are discussed in a broader context and conclusions are drawn.

DATA AND METHODS

The satellite measurements were collected from the first Meteosat Second Generation satellite (METEOSAT-8). METEOSAT-8 is a spinning stabilized satellite in a geostationary orbit, which scans the earth's disk with a 15 minute repeat cycle. The SEVIRI instrument on board METEOSAT-8 carries three channels at visible and near infrared wavelengths, eight channels at infrared wavelengths, and one high-resolution visible channel.

The CPP algorithm retrieves CA, CPH and CWP from SEVIRI reflectances at visible (0.6 μm), near-infrared (1.6 μm) and infrared (10.8 μm) wavelengths [6]. For cloudy pixels, cloud optical thickness, particle size and cloud phase are retrieved in an iterative manner by comparing satellite observed reflectances to Look Up Tables (LUTs) of simulated cloud reflectances. The LUTs have been generated using the Doubling Adding KNMI (DAK) radiative transfer model [7, 8]. The algorithm to detect cloudy pixels originates from the MODIS cloud detection algorithm [9, 5], but has been adapted for SEVIRI (J. Riédi, private communication). CWP is defined as the sum of cloud Liquid Water Path (LWP) and cloud Ice Water Path (IWP), and is computed from the retrieved cloud optical thickness and particle effective radius.

The climate model runs are done with version 2 of the RACMO model, which is a hydrostatic limited-area model used for regional climate modeling [10] The model uses the physics package of the ECMWF-NWP (cy23r4), which has been ported into the forecast component of the HIRLAM-NWP (version 5.0.6) [11]. Cloud processes in RACMO are described by prognostic equations for cloud fraction and cloud liquid water and cloud ice. Cloud forming and dissolving processes are considered sub-grid-scale and hence parameterized, however large-scale transport of cloud properties is accounted for on the resolved scale. Sources and sinks of cloud fraction and cloud condensate are process oriented and physically based, in contrast to the more commonly applied statistical approach. Total 2D cloud cover is obtained from the vertical profile of cloud fraction by assuming random-maximum overlap within a model grid box.

EVALUATION OF RACMO CLOUD PROPERTIES

RACMO-predicted CA, CPH and CWP values are compared against corresponding values from SEVIRI over Central Europe and Northern Africa (20°W to 20°E and 30°N to 60°N). These cloud properties have been generated for the period 15 May 2004 to 15 September 2004, using hourly retrievals from SEVIRI and predictions from RACMO for solar zenith angles smaller than 72°. Unequal lengths in daytime period related to the north-south extent of the domain of interest and to the seasonal effect within the observation period are accounted for by sorting the data with respect to the fraction of the day, which is defined as the normalized time between sunrise (fraction = 0) and sunset (fraction = 1). The SEVIRI-retrieved cloud properties are aggregated into the 25x25km^2 RACMO grid.

Figure 1 presents the spatial variations in mean values of SEVIRI-retrieved and RACMO-predicted values of CA, CPH (given as the fraction of water clouds) and CWP over Europe. In general, there is good agreement between the spatial patterns of CA, CPH and CWP from SEVIRI and RACMO. The largest CA and CWP values are found over Northern Europe, while lower values are found over the Mediterranean. However, RACMO overestimates CWP by about 35%, while CA and the fraction of water clouds are underestimated by about 20%. A possible reason for the large discrepancies over the Northern Atlantic Ocean is that the weather in this region is dominated by frontal systems. For these systems RACMO predicts significantly larger CWP values (100 to 250 g m^{-2}) than SEVIRI (75 to 150 g m^{-2}).

In order to examine the diurnal cycle in relation to prevailing atmospheric conditions, we focused the study on different subdomains that are representative for different climate regions. The subdomains cover an area of 15x15 RACMO grid boxes (~375x375 km^2), and are labeled North Atlantic Ocean (NAO), South Atlantic Ocean (SAO), Continental Europe (CON), and Mediterranean Spain (MED). Table 1 presents the centre coordinates of the subdomains and the mean values of the considered cloud properties. Note that RACMO overestimates CWP for most subdomains, while LWP is slightly underestimated for all subdomains. Figure 2 presents the diurnal cycles of RACMO-predicted and SEVIRI-retrieved cloud properties for the SAO and MED subdomains. These diurnal cycles are evaluated for the 25th (P25) and 50th (P50) percentile of CA, the mean value of the percentage of water clouds (CPH) and 75th (P75) and 90th (P90) percentile of CWP. In the SAO subdomain, the dominating cloud type is stratocumulus, for which the diurnal cycle is characterized by a cloud layer which gradually thickens during the night and thins during the day due to short-wave radiative absorption and decoupling from the ocean surface layer. Although the diurnal cycles of CWP from SEVIRI and RACMO are very similar for the SAO-subdomain, the mean CWP values from RACMO are 10 to 20 g m^{-2} larger than the SEVIRI values. In the MED subdomain the summertime diurnal cycles of CWP are dominated by convective clouds that strongly respond to the diurnal cycle of the land surface temperature. The strongest convection is typically found in the afternoon. After local solar noon (fraction = 0.65) the difference between SEVIRI observed and RACMO-predicted CWP values is largest (~ 75 g m^{-2} for P90). The maximum CWP in RACMO is found to occur distinctly before the end of the daytime period (fraction = 0.65), whereas SEVIRI indicates that CWP continues to rise until at least sunset (fraction = 0.75). We suggest that the overestimation of CWP by RACMO is caused by too early onset of the convection scheme, which causes an earlier onset of precipitation. This is consistent with the results of [12], who found that CWP simulations from Single Column Models (SCMs), including RACMO, are too active. The diurnal cycles of CPH show a gradual decrease of the percentage of water clouds in RACMO and SEVIRI. However, RACMO underestimates the percentage or water clouds by about 30% as compared to SEVIRI.

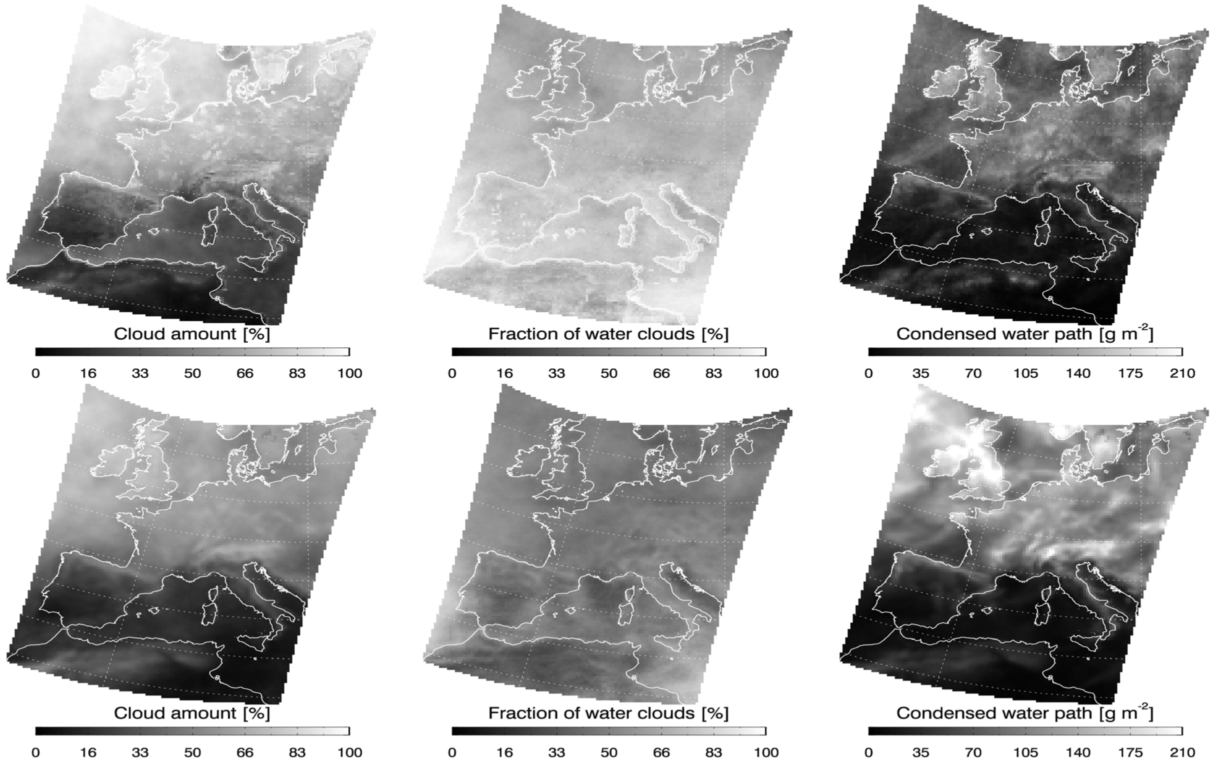

FIGURE 1. SEVIRI-retrieved (upper panel) and RACMO-predicted (lower panel) mean CA, CPH (given as the fraction of water clouds) and CWP over Europe during the period 15 May to 15 September 2004 using cloudy and cloud free pixels. In RACMO the fraction of water clouds represents the percentage of clouds with cloud temperatures larger than 250K.

TABLE 1. Centre coordinates of the subdomains and the mean values of CA, CPH (given as the fraction of water clouds), CWP and LWP during the observation period. The LWP values represent mean values for conditions where both RACMO and SEVIRI inferred water clouds.

	Subdomain		***SEVIRI***				***RACMO***			
	Lat	***Lon***	***CA***	***CPH***	***CWP***	***LWP***	***CA***	***CPH***	***CWP***	***LWP***
	deg.	*deg.*	*%*	*%*	*g m^{-2}*	*g m^{-2}*	*%*	*%*	*g m^{-2}*	*g m^{-2}*
SAO	46.4 ° N	8.6 ° W	66.4	74.6	62.4	33.9	55.6	61.5	71.7	46.4
NAO	58.8 ° N	12.1 ° W	93.8	64.7	88.9	62.2	78.2	54.9	176.1	97.1
MED	38.8 ° N	3.8 ° W	25.5	84.9	28.6	5.7	22.6	48.1	26.5	10.2
CON	50.1 ° N	18.1 ° E	73.8	71.1	87.7	42.6	58.1	53.5	117.2	58.4

CONCLUSIONS

This paper presents the evaluation of diurnal cycles of CA, CPH and CWP predicted in the Regional Climate Model (RACMO) using corresponding SEVIRI observations. Thanks to the use of SEVIRI observations, this evaluation could be performed, for the first time, over both land and ocean surfaces. Over Europe, the RACMO predictions of CWP are about 35% larger than the SEVIRI retrievals, while the percentages of water clouds and CA values are about 20% lower. However, the spatial variations in RACMO-predicted and SEVIRI-retrieved CA and CWP are similar both for the mean values. From a more detailed evaluation per climate zone it is concluded that RACMO overestimates convection in the Mediterranean as compared to SEVIRI. Moreover, the SEVIRI observations indicate that RACMO predicts maximum convection about two hours too early in these climate zones. Over Ocean the diurnal cycles of RACMO-predicted and SEVIRI-retrieved CA and CWP are similar in their mean values and in their time of reaching the maximum value.

In conclusion, this study shows that satellite retrieved diurnal cycles of cloud properties provide a powerful tool for identifying climate model deficiencies. With four years of SEVIRI data available, the evaluation of diurnal cycles shall be repeated for different years. Such a study would further increase our understanding on the response of climate models to switches between surface types and weather conditions, which are in particular important for North- Western Europe.

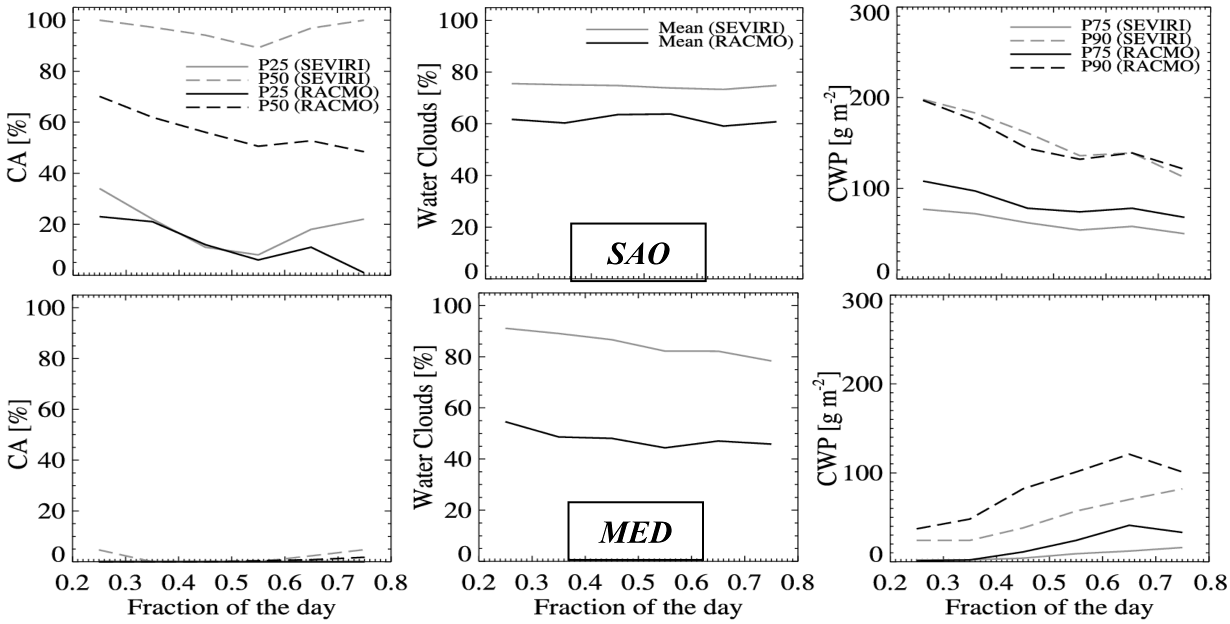

FIGURE 2. Examples of diurnal cycles of SEVIRI and RACMO inferred CA, CPH and CWP values for the South Atlantic Ocean (SOA) and the Mediterranean (MED) subdomains.

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