CLOUD PROPERTIES DERIVED FROM SEVIRI AND MODIS: A COMPARISON STUDY

Maria João Costa[1,2], **Elsa Cattani**[2], **Vincenzo Levizzani**[2] **and Ana Maria Silva**[1]

[1]Department of Physics and Évora Geophysics Centre, University of Évora,
Rua Romão Ramalho 59, 7000 Évora, Portugal
[2]Institute of Atmospheric Sciences and Climate (ISAC-CNR), Via Gobetti 101, 40129 Bologna, Italy

ABSTRACT

A methodology for the retrieval of cloud properties from multi-spectral satellite measurements was developed and its application to measurements from the MODerate Resolution Imaging Spectroradiometer (MODIS) onboard the Terra and Aqua spacecrafts was shown by Costa et al. (2003, 2004). Cattani et al. (2003) successfully compared the retrieved cloud properties with those obtained from in situ measurements and independent algorithms.

Low Earth Orbit (LEO) satellite sensors have been normally used for these studies, since they were the only source of the necessary multi-spectral measurements. Perspectives have recently been enhanced by the launch of Geostationary Earth Orbit (GEO) satellites with refined sensors onboard. In particular, the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on the first METEOSAT Second Generation (MSG1), renamed to Meteosat-8, provides spectral information comparable to that measured by the last generation of LEO satellite sensors. In addition, the use of Meteosat-8 SEVIRI measurements takes advantage of a greatly improved repeat cycle (15 min.) that allows for a global monitoring of cloud properties.

The above-mentioned methodology is based on visible, near infrared and thermal infrared satellite measurements to retrieve cloud microphysical properties, such as cloud optical thickness and droplet effective radius, and is now applied to SEVIRI spectral measurements. Data from the MODIS sensor onboard the Terra and Aqua satellites, spatially and temporally coincident with the Meteosat-8 SEVIRI images, are also analysed using the same methodology. The purpose is to evaluate the impact on the retrieval of the use of data from different spacecrafts, viewing angles and resolution, specifically those from SEVIRI. This is important in view of possible operational applications of the retrievals from the GEO orbit. In fact, an assessment of the accuracy is to be given in order to convince operational meteorologists to make use of very powerful, but rather complex microphysical products.

1. INTRODUCTION

Clouds are a major driving force of the climate system, controlling the planetary albedo. They strongly modulate the energy balance of the Earth through absorption and scattering of solar radiation and absorption and emission of terrestrial radiation, and they regulate, together with precipitation, the hydrological cycle. Although the importance of clouds is widely recognised, their impact is associated with great uncertainties due to the complexity and space-time variation of cloud phenomena. Early investigations have focused on the importance of total cloud cover, neglecting the effect of cloud type variation, nevertheless, it is now clear that both can equally contribute to determine the cloud effects on climate Therefore, the global monitoring of the cloud optical and microphysical properties becomes a main task/necessity.

Remote sensing of cloud properties such as cloud optical thickness and / or droplet effective radius using multi-wavelength radiometers flying on aircrafts began in the early 1970s (Hansen and Pollack 1970). These kinds of studies were then extended to satellite measurements (Curran and Wu 1982; Rossow and Schiffer 1991; Nakajima and King 1990; Nakajima and Nakajima 1995), aiming at providing global coverage of cloud properties. However, the accuracy introduced by the multi-wavelength information obtained from the LEO satellites is offset by the fact that these satellites do not ensure adequate space-time coverage of the globe, which is undoubtedly provided by GEO satellites, whose radiometers, however, were until now restricted to broadbands in the visible and infrared spectral regions.

The development of the methodology used here to derive cloud properties (Cattani et al. 2003; Costa et al. 2004) was encouraged by the existence of a new generation of GEO satellite measurements such as those of SEVIRI flying on Meteosat-8 (Schmetz et al. 2002). This innovative sensor opens new perspectives with respect to past and present GEO systems since it provides the necessary additional spectral measurements, supplied until now exclusively by LEO satellite sensors. The doubled sampling frequency and improved spatial resolution prompts for global monitoring of cloud properties, facilitating the task of comparing the derived cloud properties with independent measurements that allow for the error estimation, constituting the quality control of global satellite products.

The methodology for the characterization of the cloud microphysical / optical properties is based on satellite multi-spectral measurements in the visible (VIS), thermal infrared (IR), and near IR (NIR) spectral regions, used in combination with radiative transfer calculations to retrieve the cloud optical thickness, particle effective radius and cloud top temperature. A fundamental part of the method relies on the cloud properties retrieval model described by Nakajima and Nakajima (1995). The cloud characterisation scheme is applied to several SEVIRI full disk images and results are compared with coincident results obtained applying the same methodology to MODIS data, which present comparable spectral channels in the VIS, IR, and NIR. The purpose of this comparison is the evaluation of the impact that the use of data from different spacecrafts may have on the retrievals. This is important in view of possible operational applications of the retrievals from the GEO orbit.

The next section briefly describes the methodology. The results obtained along with their discussion are presented in section 3 followed by the conclusions in section 4.

2. METHOD

The methodology is described in detail by Costa et al. (2003, 2004), therefore only a brief description is provided in this section. Initially the satellite images are analysed in order to detect cloud and determine the cloud particle phase (liquid water or ice), assuming that clouds at one time are made of either liquid water or ice particles, hence no mixed phase clouds are considered in the study. The selection relies on thresholds determined from the histogram analysis of the VIS radiance and IR brightness temperature, both obtained from the images under analysis.

The VIS, NIR and IR radiance measurements corresponding to the cloudy pixels classified as liquid water or ice are used to retrieve cloud optical thickness, cloud effective radius and cloud top temperature using the algorithm proposed by Nakajima and Nakajima (1995) and Kawamoto et al. (2001). The algorithm relies on the comparison between the modelled cloud radiances in the three spectral bands and the corresponding satellite radiance measurements corrected to yield the cloud signal. The modelled cloud radiances, as well as the corrections applied to the satellite radiance measurements are obtained from radiative transfer calculations, using the radiative transfer code RSTAR (Nakajima and Tanaka, 1986, 1988). The radiative transfer code is used to pre-compute Look-Up Tables (LUTs). The LUTs contain the radiative quantities necessary for the cloud properties retrieval, namely the cloud reflected radiances and spherical albedo in the VIS and NIR spectral bands, the atmospheric and cloud transmission in the VIS, NIR and IR spectral bands, and the reflection and atmospheric emitted radiation in the NIR and IR spectral bands. The LUTs were built for a grid of selected values of the cloud optical thickness, cloud effective radius, cloud top temperature, equivalent water vapour above the cloud, equivalent water vapour of the cloud layer, solar zenith, satellite zenith and relative azimuth angles (Costa et al. 2004). These values are chosen to gradually range between the physically acceptable values for any of the quantities and therefore all physically possible solutions are considered. The cloud is characterised by a lognormal size distribution and mean values of the surface temperature and reflectance are taken. Three sets of LUTs were built differing in the standard atmospheric vertical profiles considered: Tropical, Mid-Latitude Summer and Mid-Latitude Winter, all taken from McClatchey et al. (1971).

The methodology is applied to several SEVIRI full disk images, as well as to data from MODIS sensor (Barnes et al., 1998) onboard Terra and Aqua satellites, which present comparable spectral channels in the VIS, IR, and NIR (see Table 1). The cloud top properties derived from SEVIRI measurements (cloud optical thickness, effective radius and top temperature) are compared with the same properties retrieved (using the same methodology) from MODIS measurements. For this purpose, the cloud properties (from both satellite sensors: SEVIRI and MODIS) are averaged over coincident cells of 0.1° × 0.1° and compared within the best time coincidence (see Table 2). The comparison is quantified through the computation of the relative differences between the cloud properties obtained from SEVIRI and those obtained from MODIS, defined as:

$$Difr = \left| \frac{X^{SEVIRI} - X^{MODIS}}{X^{SEVIRI}} \right| \times 100 \qquad (1)$$

SEVIRI		MODIS	
Spectral Channel (μm)	**Spatial Resolution (km^2)**	**Spectral Channel (μm)**	**Spatial Resolution (km^2)**
VIS: 0.58 – 0.71	3.0 × 3.0	**VIS**: 0.61 – 0.68	1.0 × 1.0
NIR: 3.30 – 4.45		**NIR**: 3.62 – 3.96	
IR: 9.92 – 11.8		**IR**: 10.6 – 11.5	

Table 1 – Characteristics of SEVIRI and MODIS instruments.

Meteosat-8		Terra		Aqua	
SEVIRI		**MODIS**			
Date	**Time (UTC)**	**Date**	**Time (UTC)**	**Date**	**Time (UTC)**
2003/02/12	13:42	-	-	2003/02/12	13:35
2003/05/23	12:12	-	-	2003/05/23	11:35
2003/10/31	11:42	2003/10/31	12:20	-	-
2003/11/11	11:57	2003/10/31	12:00	2003/10/31	11:55

Table 2 – Satellite images used.

3. RESULTS

The results obtained for the cloud top properties (optical thickness, effective radius and temperature) from SEVIRI measurements are shown in Figure 1.

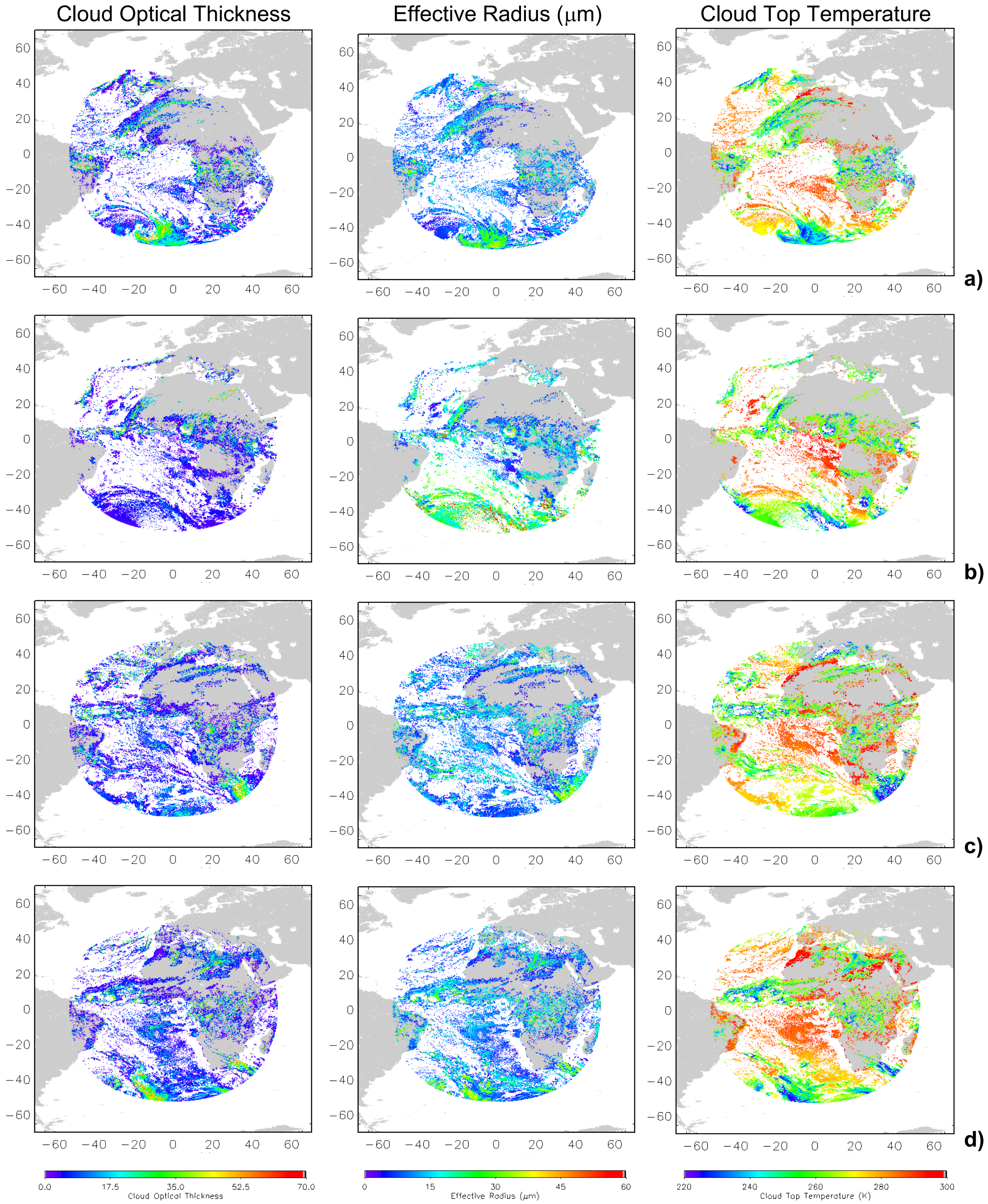
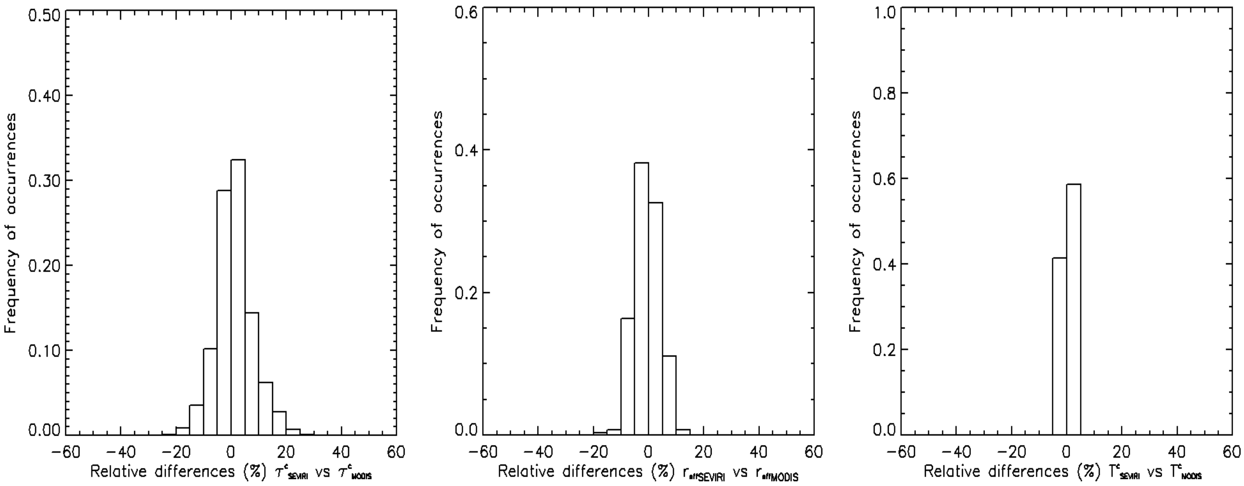


Figure 1 – Cloud optical thickness, droplet effective radius and cloud top temperature retrieved from SEVIRI measurements for: **a)** 2003/02/12 13:42 UTC; **b)** 2003/05/23 12:12 UTC; **c)** 2003/10/31 11:42 UTC; **d)** 2003/11/11 11:57 UTC.

Figure 2 shows the frequency histograms of the relative differences obtained from equation 1, between the cloud properties retrieved from SEVIRI and from MODIS. Only values of the cloud optical thickness between 4 and 40 and of the effective radius between 4 μm and 40 μm are used, in order to compare the cases where the retrieval errors are likely to be smaller (Nakajima and Nakajima 1995; Cattani et al. 2004).



a) **b)** **c)**

Figure 2 – Frequency histograms of the relative differences between the cloud properties obtained from SEVIRI and those obtained from MODIS for: **a)** cloud optical thickness; **b)** droplet effective radius; **c)** cloud top temperature.

The relative differences obtained for the cloud properties under study are generally low. In the case of the cloud optical thickness (Figure 2a), the differences are within ± 25%. As for the effective radius, the corresponding histogram shown in Figure 2b presents higher peaks with respect to the cloud optical thickness, around smaller relative differences ranging between ± 20%. The results obtained for the cloud top temperature from both sensor measurements (SEVIRI and MODIS) are quite similar as stated by the two high histogram peaks around zero (Figure 2c), resulting in relative differences within ± 5%.

The differences obtained between the SEVIRI and MODIS retrievals can be due to the time difference between the SEVIRI and MODIS imagery used (see Table 2), since the cloud properties may change in the time lag between both measurements. In the cases analysed here, the time differences are in the worse case of 38 minutes and in the best case of 3 minutes.

The calibration of both instruments (SEVIRI and MODIS) also introduces uncertainties in the retrievals of the cloud properties as demonstrated by Cattani et al. 2004, which may contribute to the differences observed in the histograms of Figure 2.

The different spatial resolution of the instruments used (SEVIRI: 3 x 3 km^2; MODIS: 1 x 1 km^2) also difficult the task of comparing the cloud properties retrieved. In the present work the cloud properties were averaged over coincident areas of 0.1° × 0.1° and then compared. Nevertheless, the larger SEVIRI pixel may encompass a mixed cloud scenario, which is not necessarily described by the average of the cloud properties retrieved at the MODIS pixel scale.

4. CONCLUSION

A methodology to retrieve the cloud properties specifically the cloud optical thickness, the cloud effective radius (near cloud top) and the cloud top temperature, is applied to SEVIRI and MODIS multi-spectral measurements. A fundamental part of the method relies on a well-known retrieval algorithm (Nakajima and Nakajima, 1995; Kawamoto et al., 2001). Foreseen future applications of the methodology could be the monitoring (geostationary temporal and spatial scales) of cloud top microphysical / optical properties.

The comparisons between the cloud properties retrieved from SEVIRI and from MODIS revealed that the relative differences are generally low and that for the cloud optical thickness are within ± 25%. As for the droplet effective radius and the cloud top temperature, the relative differences are within ± 20% and ± 5%, respectively.

The differences found between SEVIRI and MODIS retrievals may be due to the time lag between the SEVIRI and MODIS data used (indicated in Table 2). On the other hand, the calibration of both instruments introduces undoubtedly uncertainties in the cloud properties retrieved (Cattani et al. 2004). In addition, the different spatial resolution of both instruments may contribute to the differences found since the retrievals from both instruments may refer to slightly different scenarios.

5. ACKNOWLEDGEMENTS

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