CLOUD RADIATIVE FORCING FROM SEVIRI DATA: POSSIBLE EFFECTS OF AIR POLLUTION

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ABSTRACT

Clouds are certainly the major factor regulating the Earth radiation budget. Special attention has been dedicated in the last few years to the cloud interaction with aerosol particles through modelling studies, *in situ* measurements and remote sensing techniques. The alterations that clouds undertake through the interaction with aerosols may have strong implications on the interaction with solar and terrestrial radiation, leading to different radiative forcing estimates with respect to clouds developing in “clean” atmospheric environments.
The aim of the present work is to estimate the cloud radiative forcing from SEVIRI data. The cloud properties required for this purpose are obtained from the inversion of SEVIRI spectral measurements in the visible (0.56 - 0.71 µm), near infrared (3.48 – 4.36 µm) and infrared (9.8 – 11.8 µm) channels. The derived cloud properties are in turn used in combination with a suitable radiative transfer model, to estimate the radiation fluxes and subsequently the cloud radiative forcing. The cloud radiative forcing will be estimated in European regions subject to high levels of air pollution, to establish the possible modifications induced by the presence of this type of aerosol.

1. INTRODUCTION

Clouds are certainly the major factor regulating the Earth radiation budget. Special attention has been dedicated in the last few years to the cloud interaction with aerosol particles through modelling studies, *in situ* measurements and remote sensing observations (Suzuki et al., 2004). The alterations that clouds undertake through the interaction with aerosols may have strong implications on the interaction with solar and terrestrial radiation, leading to different radiative forcing estimates with respect to clouds present in “clean” atmospheric environments.
Estimates of the instantaneous cloud radiative forcing (ICRF) are computed from Spinning Enhanced Visible and Infrared Imager (SEVIRI) data for a region of the northern Italy (44 – 46 N, 7 – 13 E, Fig. 1), particularly subjected to anthropogenic aerosol emissions due to the high concentration of urban areas and industries.

Preliminary results are shown to establish the possible modifications induced by air pollution on the cloud properties and consequently on ICRF.

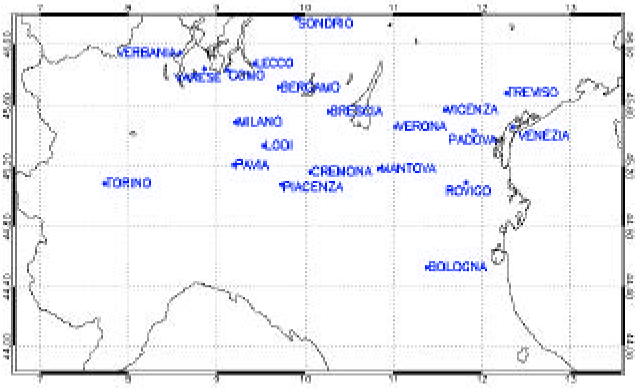

Fig. 1. Map of the region analysed. The location of the cities and towns where the PM10 were measured are reported on the map.

2. THE ANTHROPOGENIC AEROSOL OVER NORTEHRN ITALY

Two days are analysed, the 18th of February and 2nd of October 2004, selected on the basis of the different aerosol conditions. The aerosol load can be derived by means of the PM10 concentrations measured in the principal cities of the analysed region and the aerosol characterization obtained from the MODerate Resolution Imaging Spectroradiometer (MODIS) data (MOD04_L2 product, resolution 10 km; Kaufman and Tanré, 1998). It has to be taken into account that the aerosol characterization from satellite data refers to the clear (not cloudy) days nearest to the analysed days, since aerosol products are not retrieved in presence of clouds.
PM10 are solid or liquid particles in the atmosphere with diameters below 10 µm. The main sources are: carbon used in industrial and domestic combustion, gasoline and diesel, industrial processes, fires, wind erosion and volcanic eruptions. They can affect the human health by producing irritation of the respiratory system, and the plant life by interfering with photosynthesis. Another effect is the deterioration of the construction materials and other surfaces. In the atmosphere they decrease the visibility and may interfere with cloud formation and evolution.
The 18th of February 2004 is characterized by a higher aerosol load than the 2nd of October, as demonstrated by the concentrations of PM10 particles (Fig. 2a) ranging from 70 to more than 140 µm/m^3, and the values of the aerosol optical thickness (Fig. 2b) up to 1. A lower aerosol load is observed on the 2nd of October with smaller PM10 amounts (up to 105 µm/m^3, Fig. 3a) and aerosol optical thickness values (Fig. 3b). The relatively high values of the Ångström exponent (Fig. 2c and 3c) and the aerosol type (sulphate) (Fig. 2d and 3d) retrieved from MODIS data assure the anthropogenic origin of the dominating aerosol.

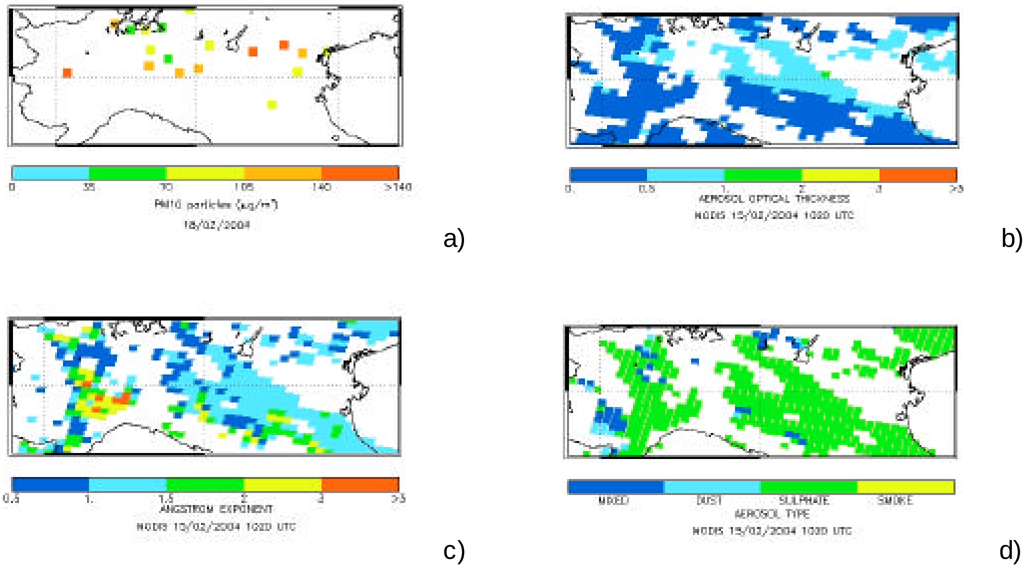

Fig. 2. Aerosol characterization for the 18th of February 2004: (a) PM10 amount measured in the cities and towns of Fig.1a, MODIS aerosol optical thickness (b), Ångström exponent (c) and aerosol type (d). The MODIS aerosol products are relative to the 15th of February, the not completely cloudy day nearest the day of the case study.

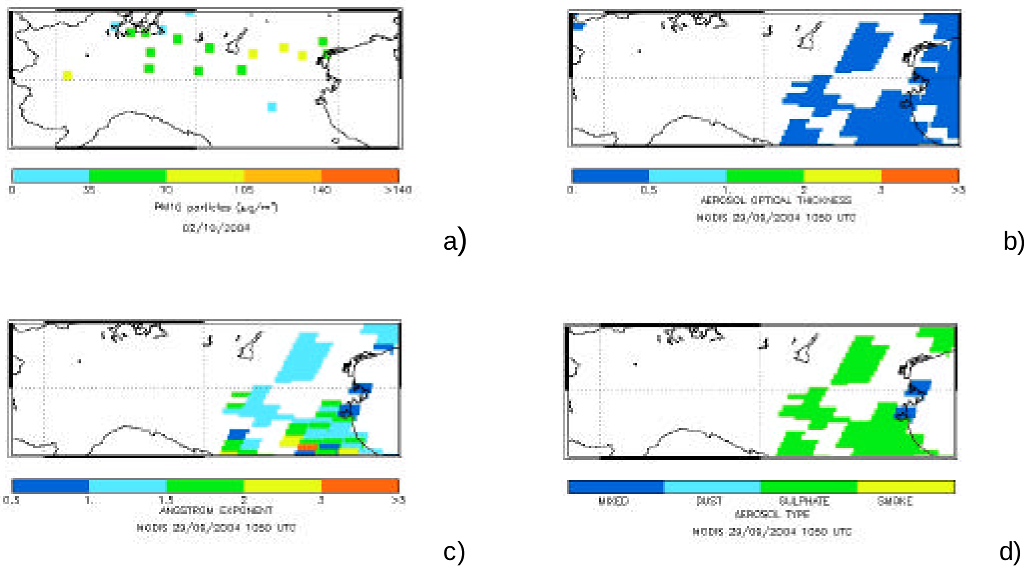

Fig. 3. Same as in Fig. 2 but for the 2nd of October 2004. MODIS aerosol products are relative to the 29th of September.

3. THE CLOUD PARAMETER RETRIEVAL AND RADIATIVE FORCING COMPUTAIONS

The characterization of the cloud coverage for the two analysed days in terms of the effective radius (R_e), optical thickness (τ) and top temperature (T_c) is obtained with the multispectral retrieval algorithm CAPCOM (Comprehensive Analysis Program for Cloud Optical Measurement, Nakajima and Nakajima, 1995; Kawamoto et al., 2001) applied to the SEVIRI radiances at 0.6, 3.9 and 10.8 µm. The algorithm relies on the comparisons between Look Up Tables (LUT) of cloud radiances computed in the three spectral channels and the corresponding satellite radiance measurements corrected to yield the cloud signals. The detection of the SEVIRI cloudy pixels and the determination of the cloud phase is performed using threshold tests for the 0.6 µm radiances and the 10.8 and 12 µm brightness temperatures. More details about the methodology for the cloud parameters retrieval can be found in Costa et al. (2003).

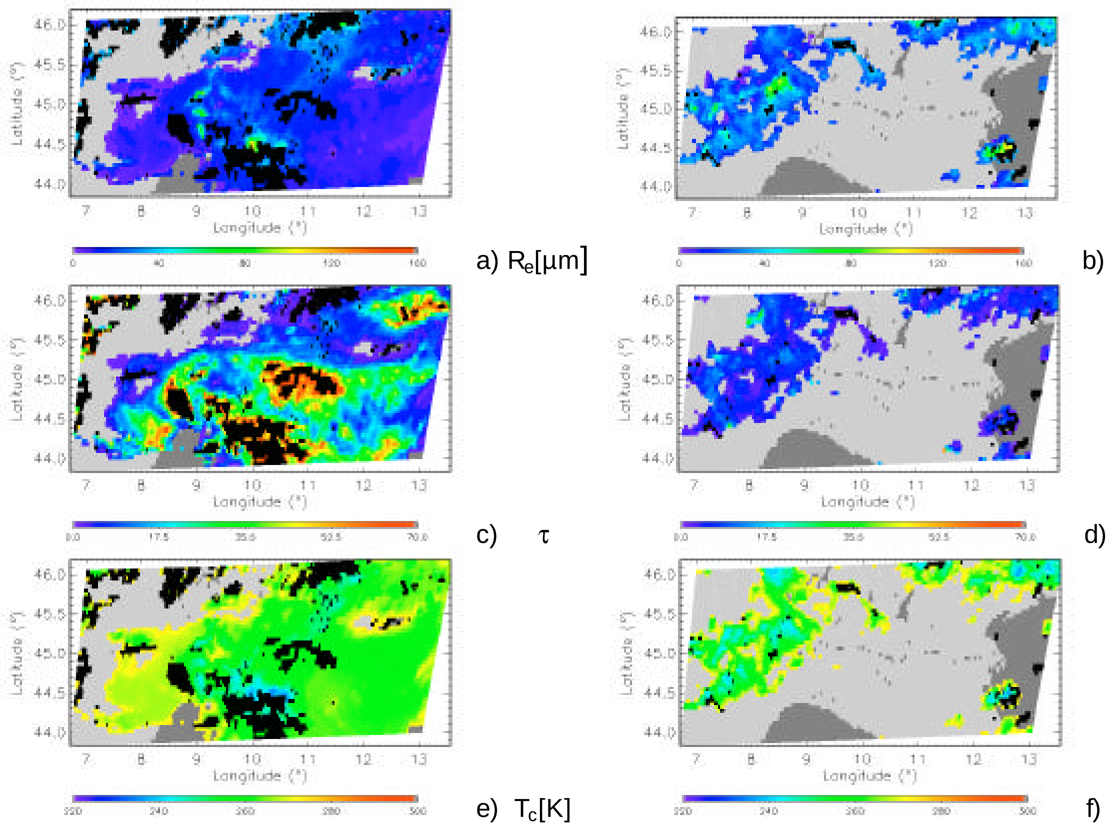

Fig. 4. Cloud parameters retrieved from SEVIRI data: 18 February 1230 UTC (left column) and 2 October 1230 UTC (right column). Light and dark grey pixels represent clear SEVIRI pixels over land and sea respectively. No reliable parameters are retrieved for the pixels coloured in black.

In Fig. 4 the maps of the retrieved cloud parameters are shown for the 18 February (left) and 2 October (right) 1230 UTC, whereas in Fig. 5 are reported the corresponding frequency distributions of R_e, τ and T_c values. Analysing these data it is possible to notice the modifications of the cloud parameters due to the presence of the aerosol particles from urban and industrial pollution. The clouds that interact with aerosol particles have lower values of R_e and greater values of the optical thickness. In particular on 18 February, the day characterized by the greater aerosol load, the majority of the SEVIRI cloudy pixels exhibits R_e values lower than 20 µm and τ values up to 40, whereas the 2 October a significant amount of pixels present R_e

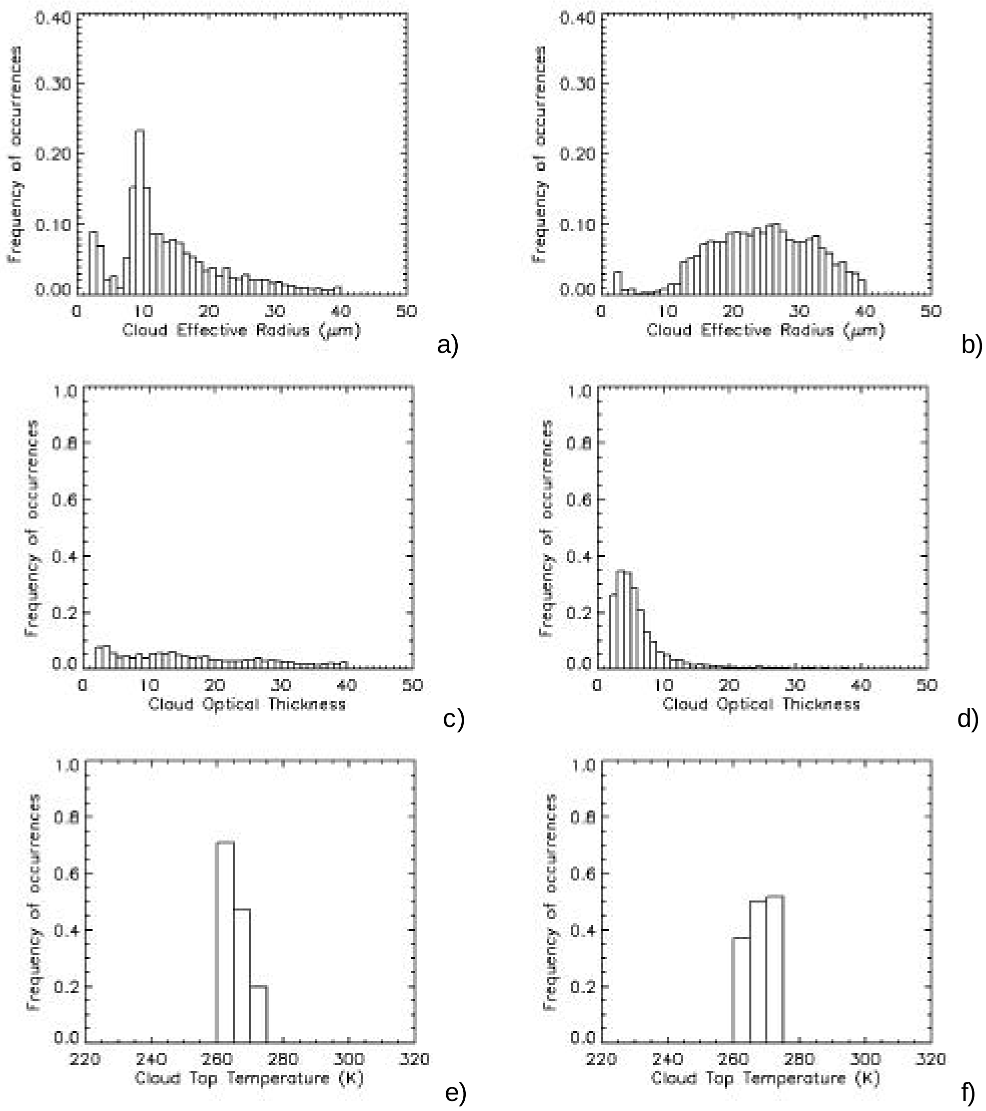

Fig. 5. Frequency distribution functions of the cloud parameters retrieved from SEVIRI data (Fig. 4) for the 18 February (on the left) and the 2 October (on the right).

values ranging from 20 to 40 µm and τ values lower than 10. Only few pixels show effective radius values lower than 10 µm, unlike what happens the 18th of February.

The action of the aerosol on the cloud effective radius can be better emphasized if only the convective clouds are selected and the dependence of R_e on T_c is analysed according to the methodology developed by Rosenfeld and Lensky (1998) (Fig. 6). Namely a convective cloud ingests air mainly through its base, so it has the highest probability of being influenced by aerosols located in the lower layers of the atmosphere. Convective clouds can be identified according to Rosenfeld and Lensky (1998) by selecting those cloudy pixels having the reflectance at 0.6 µm greater than 0.4 and the brightness temperature difference between 10.8 and 12 µm (BTD) < BTD_s + 1°C, where BTD_s is the BTD value computed in clear, water vapor saturated condition. According to the Rosenfeld and Lensky (1998) methodology the cloud top properties of a cluster of convective clouds having the top at different heights (i.e. at different stages of their vertical evolution) can be considered representative of the

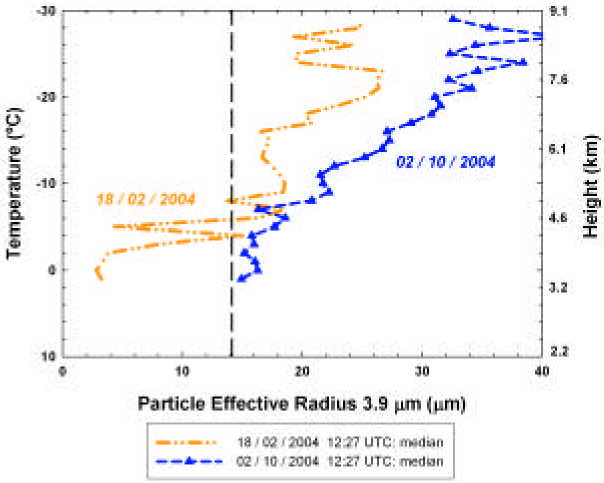

Fig. 6. Cloud top temperature as a function of the R_e for the two analysed days. The vertical dashed line indicates the 14 µm precipitation threshold described by Rosenfeld and Gutman (1994). The curves represent the 50th percentile (median).

time evolution of the individual cloud element. Thus representing R_e as a function of the cloud top temperature for the selected convective clouds gives a description of the time evolution of a growing convective cloud.

The ICRF at the top of the atmosphere (TOA) is computed for the two selected days from the net shortwave (N_{SW}) and longwave (N_{LW}) fluxes, according the following equation,

$$ICRF = (N_{SW} + N_{LW})^{cloud} - (N_{SW} + N_{LW})^{no-cloud}$$

where the net fluxes are given by the differences between the downward and upward fluxes, $N_{sw} = (SW\downarrow - SW\uparrow)$ and $N_{LW} = (LW\downarrow - LW\uparrow)$ (IPCC, 2001). A positive value of the ICRF indicates that the clouds cause a warming of the overall Earth-atmosphere system, whereas a negative value denotes a cooling of the system. The radiative fluxes were computed using FluxNet, a neural network version of the radiative transfer model Streamer (Key and Schweiger, 1998). The cloud characterization, namely phase, particle effective radius, optical thickness and top temperature to be input to the radiative transfer model is derived from SEVIRI data according to the methodology described at the beginning of this section.

The alterations of cloud properties as a consequence of the interactions with aerosols may alter significantly the radiative forcing with respect to clouds in pristine atmospheric environments (Fig. 7). Convective clouds developing in an aerosol contaminated atmosphere (red curve in Fig. 7) show a decreasing TOA ICRF that reaches very high negative values as the cloud top temperature decreases, whereas the clouds developing in the aerosol-free conditions (blue curve in Fig. 7) are characterized by positive ICRF values that increase (more positive values) decreasing T_c. Thus the trend of the TOA ICRF as a function of T_c suggests that the convective cloud systems contaminated by the urban-industrial aerosol induce a more pronounced cooling of the Earth-atmosphere system.

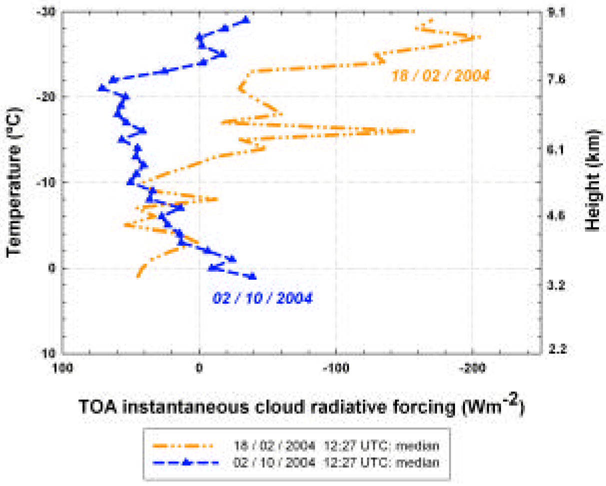

Fig. 7. Instantaneous cloud radiative forcing at TOA for the two analysed days. The curves are relative to the convective pixels selected for the Fig. 6.

4. CONCLUSIONS

The evolution of cloud top temperature and effective radius of convective clouds in the northern Italy region selected for the study indicates that clouds that come in contact with intense urban / industrial air pollution are subjected to a decrease of the effective radius and an increase in the optical thickness.

The evolution of the instantaneous cloud radiative forcing at the TOA reveals that the clouds corresponding to the higher pollution levels reflect more radiation to space than the "clean" ones for temperatures below -10ºC.

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