A NEW ALGORITHM TO DETECT DESERT DUST OUTBREAKS USING MSG-SEVIRI DATA

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Abstract

The strong impact of dust outbreaks on human activities has significantly increased the interest of scientific community in developing efficient monitoring systems capable of detecting them, supporting activities devoted to mitigate their effects. In this work, the performances of an innovative algorithm for dust detection, named RST_{DUST}, based on the successful Robust Satellite Techniques (RST) multi-temporal approach, are further assessed, analyzing some intense Saharan dust outbreaks which affected Mediterranean region in May 2008. This algorithm is further experimented here analyzing data provided by SEVIRI (Spinning Enhanced Visible and Infrared Imager), which offers the opportunity of promptly detecting dust events (close to the source) and of monitoring their space-time evolution in real time, thanks to its temporal resolution of 15 minutes. Outcomes of this study, which are compared to some independent ground- and satellite-based aerosol products, confirm that RST_{DUST} may represent an effective tool for automatically identifying Saharan dust from space both over land and sea areas. This work encourages further experimentations of such an algorithm in different geographic regions by using different satellite sensor data, to better assess its potential in monitoring dust events in operational contexts.

INTRODUCTION

Dust outbreaks are meteorological phenomena having strong implications on climate, environment and human activities. Saharan dust injected into the atmosphere may contribute to the climate changes (Winckler et al., 2008; Yue et al., 2009), and may also determine several other issues, including problems to the human health (Chen et al., 2004). Because of their effects, there is a growing interest of scientific community in better analyzing and monitoring dust events. In this context, the contribution of satellite remote sensing in studying and monitoring these meteorological phenomena is particularly important. Data provided by high temporal resolution sensors as SEVIRI (Spinning Enhanced Visible and Infrared Imager) if properly processed, and integrated with information furnished by ground-based systems (e.g. lidar data), may be indeed effectively used to track and characterize dust outbreaks also in the framework of operational early warning systems.
To detect Saharan dust from space several methods have been proposed through the years (e.g. Ackerman, 1989, 1997; Gu et al., 2003; Luo et al., 2003; Schepanski et al., 2012). Many of these techniques exploit the reverse absorption behaviour shown by silicate particles (the main minerals in the Saharan dust) at 11 and 12 μm wavelengths (split-window), in comparison with ice crystal and water droplets typical of meteorological clouds (Prata, 1989). However, these methods, which generally apply fixed thresholds tests to the $\Delta T=T_{11}-T_{12}$ brightness temperature difference (e.g. Ackerman, 1997; Legrand et al., 2001; Gu et al., 2003; Luo et al., 2003; Zhao et al., 2010), generally not guarantee the same performances level under different observational conditions (e.g. different atmospheric water vapour content, nature of the background, specific aerosol properties) as well as in different geographic areas (see Sannazzaro et al., 2014a). More advanced methods have shown that improvements in dust outbreaks identification from space are definitively possible, although some limitations still remain (e.g. Klüser et al., 2009; Good et al., 2012; Schepanski et al., 2012; Ashpole et

al., 2013; Gaiero et al., 2013). Among these methods, the RST technique not using empirical thresholds and not requiring any ancillary data may be particularly suitable for monitoring Saharan dust from space in operational scenarios (Sannazzaro et al., 2014a). This technique, which has already demonstrated better performances than traditional split window methods (Sannazzaro et al., 2014a), has recently been optimized to further increase its performances in correctly discriminating dust from different features (Sannazzaro et al., 2014b). In this work, such an algorithm (that was christened RST_{DUST}) is further tested, using data provided by SEVIRI (Spinning Enhanced Visibile and Infrared Imager), on a recent dust event affecting the Mediterranean region in May 2008. Results of this study are shown and discussed in detail in the following sections.

RST_{DUST}

The RST_{DUST} algorithm represents a specific configuration of the Robust Satellite Techniques (RST) multitemporal approach (Tramutoli 1998; 2005), specifically tailored to detect dust outbreaks from space. This algorithm computes three local variation indexes in combination to identify Saharan dust on satellite imagery (Sannazzaro et al., 2014b). These indexes are respectively defined as:

$$\otimes_{\Delta TIR}(x,y,t) \equiv \frac{\lfloor (T_{11}(x,y,t) - T_{12}(x,y,t)) - \mu_{T11-T12}(x,y) \rfloor}{\sigma_{T11-T12}(x,y)} \quad (1)$$

$$\otimes_{TIR}(x,y,t) \equiv \frac{\lfloor T_{11}(x,y,t) - \mu_{T11}(x,y) \rfloor}{\sigma_{T11}(x,y)} \quad (2)$$

$$\otimes_{VIS}(x,y,t) \equiv \frac{\lfloor R_{VIS}(x,y,t) - \mu_{VIS}(x,y) \rfloor}{\sigma_{VIS}(x,y)} \quad (3)$$

Where $T_{11}(x,y,t)$ - $T_{12}(x,y,t)$ is the brightness temperature difference of the signal measured at 11 and 12 μm wavelengths, while $\mu_{T11-T12}$(x,y) and $\sigma_{T11-T12}$(x,y) respectively represent the corresponding temporal mean and the standard deviation computed on pluriannual time series of satellite records collected in similar observational conditions (same month, same acquisition time). The terms μ_{T11}(x,y) and $\sigma_{T11}(x,y)$ have the same meaning as before, but in reference to $T_{11}(x,y,t)$ brightness temperature. $R_{VIS}(x,y,t)$ is instead the radiance measured in the visible band, at around 0.6 μm wavelength, while $\mu_{VIS}(x,y)$ and $\sigma_{VIS}(x,y)$ are the correspondent temporal mean and standard deviation.
The $\otimes_{\Delta TIR}(x,y,t)$ index, which analyzes signal measured in the split window bands, is particularly sensitive to the presence of silicate particles in the atmosphere (see Tramutoli et al., 2010; Sannazzaro et al., 2014a). The $\otimes_{TIR}(x,y,t)$ index is used to better filter out meteorological clouds over the analyzed satellite scenes, while the $\otimes_{VIS}(x,y,t)$ index, which takes into account the reflectance of dust aerosols in the visible band, is used to further increase the confidence level of detection in daytime data (Sannazzaro et al., 2014b). RST_{DUST} is a tuneable technique, therefore different cutting levels of its indexes (especially of $\otimes_{\Delta TIR}(x,y,t)$, more sensitive to the dust) can be used to provide information about regions characterized by a different probability of dust presence in the atmosphere.

RESULTS

To study the dust events analyzed in this work, hundreds of SEVIRI sub-scenes (of 725 × 533 pixels in size), acquired between 2004 and 2007, were processed. The generated RST_{DUST} maps report, in different colours, the areas that, according to the indexes reported above, were characterized by a lower (orange pixels) or higher (brown pixels) probability of dust presence in the atmosphere. The EUMETSAT cloud mask product (EUMETSAT, 2007; EUMETSAT 2010) was instead used as a background to the generated dust maps, in order to emphasize areas affected by meteorological clouds. During 18-23 May 2008, an intense dust storm coming from the Sahara dispersed over Europe and Greece (Amiridis et al., 2009). Fig 1a reports the RST_{DUST} map of 18 May at 12:00 GMT showing that, at time of analyzed satellite observation, the Saharan dust was affecting North Africa and Southern Italy, as well as part of Mediterranean sea. To better assess quality of RST_{DUST} detections, the dust loading forecast map, independently generated by the BSC/DREAM Model (Barcelona Supercomputing Canter/Dust Regional Atmospheric Model; BSC-DREAM, 2013), for the same day and same hour of observation, is reported in Fig. 1b. The comparison of RST_{DUST} map with this independent dust forecast product shows that detected and forecasted dust areas were in general compatible (see the region included within the black rectangle of Fig. 1b, corresponding to the area covered by the SEVIRI sub-scene). This is particularly evident looking, for instance, at Southern Italy and Mediterranean sea, where higher was probability of dust presence in the atmosphere according to RST_{DUST}, and where a higher dust loading was forecasted by the BSC/DREAM Model. Main differences between the two products can be observed instead especially over part of North Africa, Italy and Central Europe, where the dust signature in the split window bands was presumably obscured by the meteorological clouds affecting the aforementioned regions (see pixels in gray over the map of Fig. 1a).

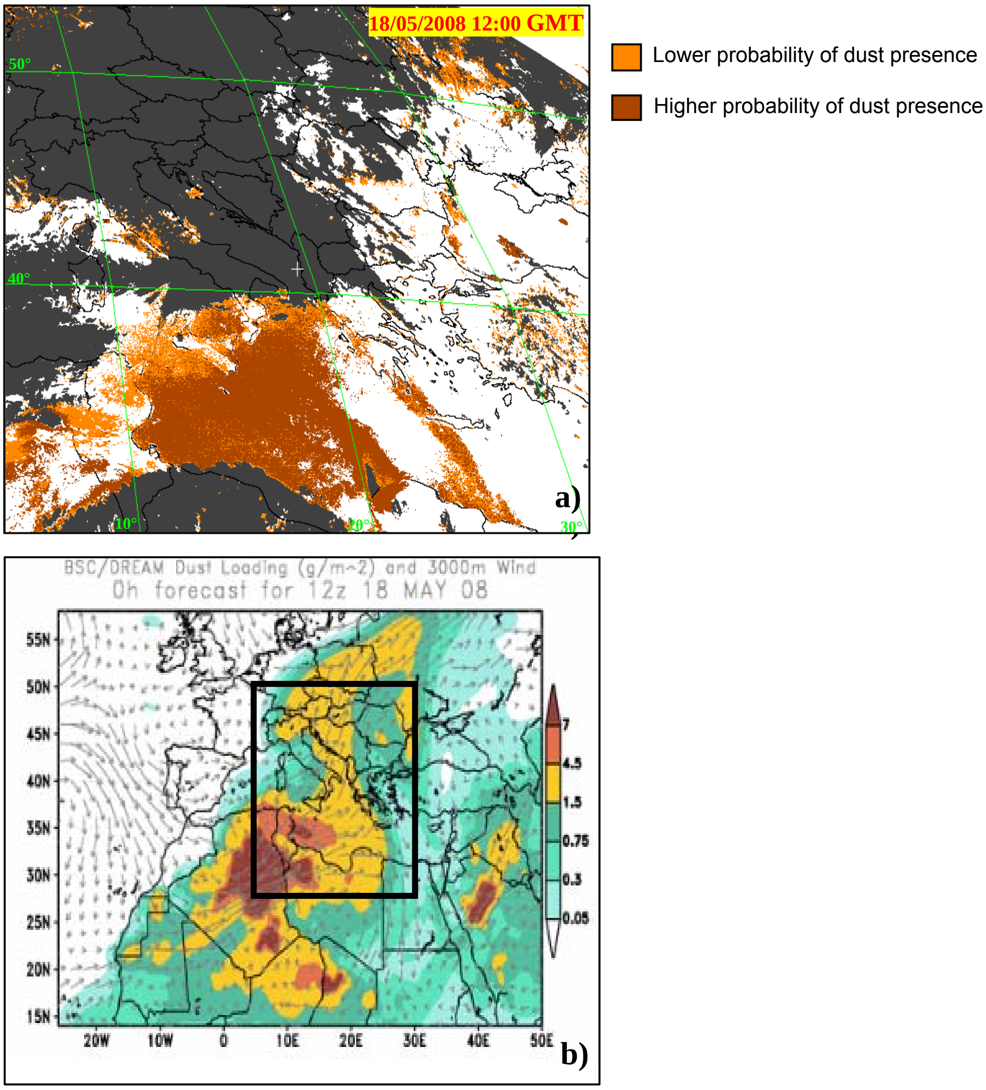

Figure 1: a) RST_{DUST} map of 18 May 2008 at 12:00 GMT generated using values of $\otimes_{VIS}(x,y,t) > 0$ (land), > 1 (sea), AND $\otimes_{TIR}(x,y,t) > -2$ AND $\otimes_{\Delta TIR}(x,y,t) < 0$ (orange pixels), and of $\otimes_{VIS}(x,y,t) > 0$ (land), > 1 (sea), AND $\otimes_{TIR}(x,y,t) > -2$ AND $\otimes_{\Delta TIR}(x,y,t) < -1$ (brown pixels); b) forecast map of dust loading for the same day and time of analyzed satellite observation (BSC-DREAM, 2013).

To further assess RST_{DUST} performances in daytime conditions another dust event, which occurred between 27 and 30 May 2008 affecting Italy and Central Europe (Papayannis et al., 2009; Klein et al., 2010), is also analyzed here. Fig. 2a reports the RST_{DUST} map of 28 May 2008 at 12:00 GMT showing the presence of Saharan dust over Central and Southern Italy, as well as over part of the Mediterranean sea. More in detail, the RST_{DUST} map of Fig. 2a shows the presence of dust also over Naples (indicated by the green cross within the blue circle over the dust map), where a lidar measurement was independently performed the same day between 12:07-12:38 GMT, and was made freely available online by the European Aerosol Research Lidar Network (EARLINET, 2013). The lidar profile shown in Fig. 2b, reporting values of aerosol backscattering coefficient [m-1 sr-1] at 532 nm, confirms that an aerosol layer was actually present in the atmosphere over Naples, at time of analyzed satellite observation, well corroborating the RST_{DUST} detection. In addition, the BSC/DREAM dust forecast product reported in Fig. 2c shows that forecasted dust areas were once again compatible with those detected by satellite, except for the regions where a conspicuous cloud coverage probably impacted on dust identification from space.

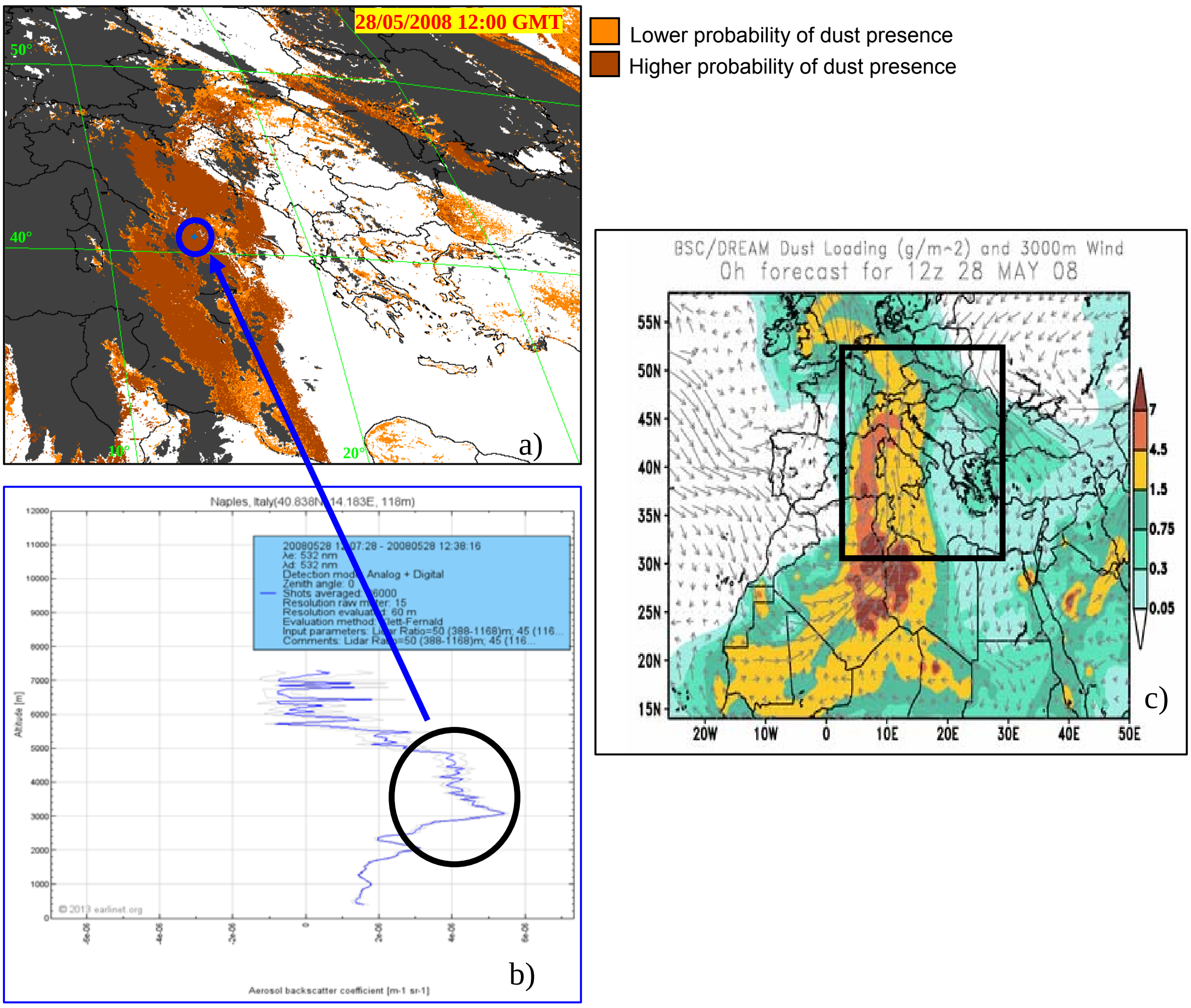

Figure 2: a) RST_{DUST} map of 28 May 2008 at 12:00 GMT generated using values of $\otimes_{VIS}(x,y,t)$ > 0 (land), > 1 (sea), AND $\otimes_{TIR}(x,y,t)$ > -2 AND $\otimes_{\Delta TIR}(x,y,t)$ < 0 (orange pixels), and of $\otimes_{VIS}(x,y,t)$ > 0 (land), > 1 (sea), AND $\otimes_{TIR}(x,y,t)$ > -2 AND $\otimes_{\Delta TIR}(x,y,t)$ < -1 (brown pixels); b) vertical profile of the aerosol backscattering coefficient (m^{-1} str^{-1}) at 532 nm, performed on 28 May 2008 at the EARLINET station of Naples between 12:07-12:38 GMT; c) dust forecast map for 28 May 2008 for the same day and time of analyzed satellite observation (BSC-DREAM, 2013).

These results extends the outcomes of a previous analysis (Sannazzaro et al., 2014b), where the RST_{DUST} algorithm was proposed and for the first time tested, and where its potential in monitoring dust events in real time, exploiting the high temporal resolution of SEVIRI (15 minutes), was also assessed. They confirm the capabilities of the algorithm used in this work in correctly discriminating dust from meteorological clouds from space, encouraging further experimentations of RST_{DUST} on different geographic areas, as well as o different satellite sensor data both polar and geostationary.

CONCLUSIONS

In this paper, the performances of the recent RST_{DUST} algorithm in identifying dust outbreaks have been further assessed, analyzing some important dust events which affected Europe and Mediterranean regions in May 2008. In particular, the RST_{DUST} maps, generated processing daytime SEVIRI data, have been compared to those provided by independent forecast (BSC-DREAM) and ground-based (EARLINET) aerosol products.
Results of this study confirm the capabilities of RST_{DUST} in successfully detecting Saharan dust in the atmosphere both over land and sea areas, thanks to a high confidence level of detection that, in daytime conditions, is assured also by the use of a local variation index which analyzes signal measured in the visible channel of SEVIRI, centred at around 0.6 µm.
Moreover, this study further demonstrates the high potential offered by RST_{DUST} in correctly discriminating dust from different features (as the meteorological clouds), as well as in timely detecting Saharan dust in the atmosphere, giving an important contribution for better mitigating impact of dust outbreaks on both social and economic human activities.

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