SATELLITE REMOTE SENSING FOR MONITORING AEROSOL DUST EVENTS: A CASE STUDY OF APRIL 17, 2005

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Abstract. - This paper presents the results from the use of satellite remotely sensed imagery (NOAA-AVHRR, AQUA MODIS) for the detection and mapping of aerosol dust events. For this purpose, an intense aerosol dust event was used, mainly associated with dust transferred over the area from the Saharan desert. This occurred on April 17, 2005, covering most parts of Greece. The results depict the potentiality of the use of remotely sensed data for monitoring and air pollution quality mapping at a full extent, providing useful information that could be used in combination with other available data sources (such as meteorological data and air pollution data from ground based monitoring stations).

Key-words:- dust, aerosol, Sahara, AQUA MODIS, NOAA-AVHRR, remote sensing.

1 Introduction

Aerosol particles play an important role in climate and atmospheric chemistry. Satellite remote sensing has been used for recording aerosol since the late 1970s. The Advanced Very High-Resolution Radiometer (AVHRR) onboard NOAA satellite was mostly used for deriving aerosol properties, especially over the ocean [1,2,3], followed by TOMS (Total Ozone Mapping Spectrometer). Its capability was the detection of elevated absorbing aerosols over both land and ocean by using UV spectrum in the range 0.34 - 0.38μm [4,5].

During the last decade several studies have been performed on air quality monitoring using remote sensing [6,7,8].

Moderate Resolution Imaging Spectrometer (MODIS) on board Earth Observing System (EOS) satellites [9] has focused on the systematic global retrieval of aerosol properties both over land and sea. MODIS-derived aerosol properties over land [10,11] in tandem with those over ocean [12,13,14] enable us to comprehensively study the global aerosols.

Saharan dust has also received considerable attention because it provides the strongest aerosol signature in satellite retrievals of the aerosol optical depth and perturbation to the clear sky radiation budget over oceanic regions [15,16]. The occasional transport of particles from the Sahara desert is particularly important for countries in the southeast Mediterranean region, such as Greece.

Remote sensing has been widely used for dust event studies, especially over oceans [17,18]. TOMS data have been systematically used in studying the spatial distribution of dust particles [19,20].

Nikitopoulou and Cartalis [21] focused on the combined use of satellite and ground-based data for assisting forecast of atmospheric pollution events. Michaelides *et al.* [22] and Lachanas *et al.* [23] examined dust events including recording and characterization with the use of METEOSAT imagery and the verification of *in-situ* dust measurements from a ground based network. Retalis et al. [24] presented a study of dust events in Cyprus with the combined use of TERRA/MODIS imagery and meteorological data.

The purpose of this paper is to demonstrate the capability of using appropriate satellite imagery for studying and monitoring the evolution of the intense Saharan dust event of April 17, 2005.

2 Methodology

Transfer of Saharan dust over Greece often occurs, especially during spring season. Satellite remote sensed data provide an ideal tool for mapping and tracking dust plume. For that reason, several techniques have been developed [16,17,25,26]. However, in some cases, such as the dust event on April 17, 2005, the concurrent presence of clouds does not permit the use of such techniques. Thus, photo-interpretation techniques (i.e. histogram stretching, colour-composites) could be used alternatively.

The methodology adopted in the present research consists of the following steps:

- Data collection of available satellite imagery
- Processing of remotely sensed imagery
- Description of the meteorological situation for the dust event.

2.1 Data collection

Aqua (MODIS) and NOAA (AVHRR) images acquired on April 17, 2005 were selected for monitoring the dust event.

MODIS (Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. Two bands are imaged at a nominal resolution of 250 m at nadir, with five bands at 500 m and the remaining 29 bands at 1000 m.

NOAA polar orbiting satellites are excellent platforms for observing dust events. AVHRR is a five channel scanning radiometer which measures emitted and reflected radiation in the visible (0.55–0.68μm) and reflected-infrared (0.725–1.1μm) bands and in three emitted-IR "window" channels (3.55–3.93, 10.3–11.3, and 11.5–12.5μm) of the electromagnetic spectrum, with a basic spatial resolution of 1.1 km at nadir.

Aqua MODIS imagery was acquired on April 17, 2005 at 11:40 UTC, with a resolution of 1km. NOAA–16 and NOAA–17 AVHRR raw images of 1.1 km resolution were acquired on April 17, 2005 at 12:10 and 09:10UTC, respectively. This continuation of successive image acquisition permits to track the course of the dust plume and report the areas, which are mostly affected.

2.2 Image processing

All raw images were imported to ERDAS Imagine 8.7 software [27]. Then, image rectification was applied and images were georeferenced to the UTM WGS84 (zone 34N) projection system. The appropriate band combination was performed along with histogram stretching for achieving best visualisation results. The situation of the dust event evolution is demonstrated in Figures 1-3, while for interpretation purposes, the coastline of Greece (in black) was overlaid on each image.

The algorithm for enhancement illustration of dust for MODIS imagery uses 7 of the 36 available channels to exploit the spatial and spectral contrast features of dust. Listed in terms of (channel index; central wavelength; native spatial resolution) they are as follows: (3; 0.469μm; 500m), (4; 0.555μm; 500m), (1; 0.645μm; 250m), (2; 0.853μm; 250m), (26; 1.38μm; 1km), (31; 11.0μm; 1km), and (32, 12.0μm; 1km). The over-water algorithm uses channels 2, 3, 4, and the over-land algorithm enlists all seven channels listed above.

Fig. 1 presents a false colour image composite of visible channels (0.469, 0.555 and 0.645 μm for the blue, green and red colours) for the MODIS Aqua imagery. The dust cloud is well illustrated in dark yellow covering most parts of Greece and especially Crete, Pelloponese and Attica, while the thin cloudiness also appears in white.

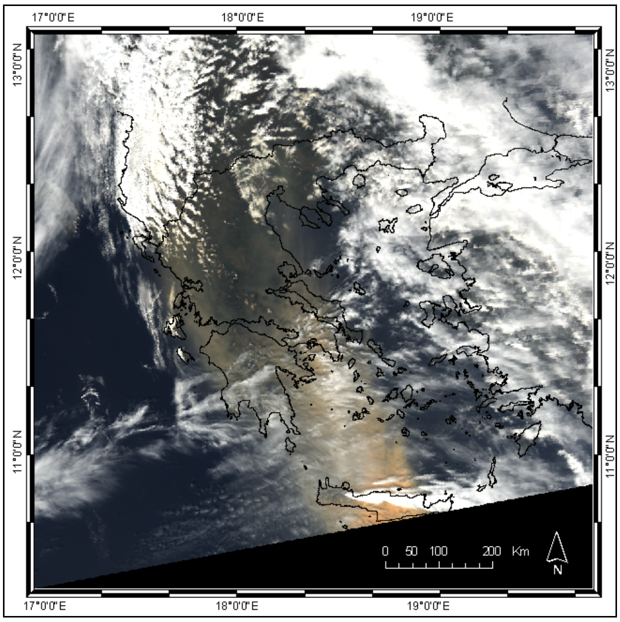

Figure 1. MODIS Aqua imagery acquired on April 17, 2005 (11:40 UTC). The image is a composite of visible channels (0.469, 0.555 and 0.645 μm for the blue, green and red colours).

NOAA-AVHRR dust storm images are generally multi-channel colour composite images created using channels 1, 2 and 4 of the NOAA satellites. In most cases, dust appears in the image as a yellow-brown haze.

However, in order to better distinguish airborne dust from water vapour clouds that may be present in the region, the so-called "split-window" technique is utilised. To accomplish this, subtraction of the data in AVHRR channel 5 from the data in AVHRR channel 4 is performed. After some histogram manipulation, the image appears greyscale with airborne dust appearing white at a brightness level directly proportional to its density in the atmosphere.

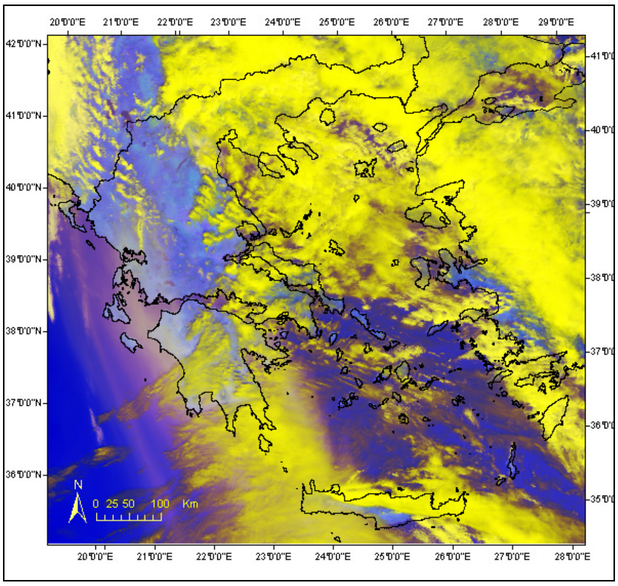

Figure 2. NOAA–17 AVHRR imagery acquired on April 17, 2005 (09:10 UTC). The image is a composite of visible and IR channels (RGB: 1,2,4).

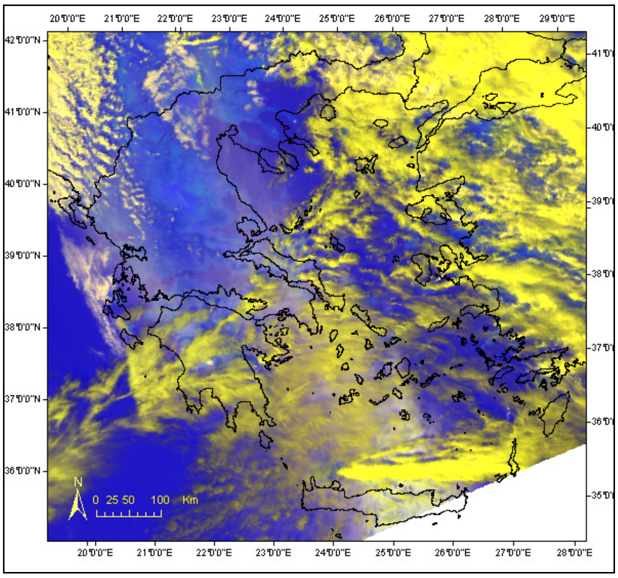

Figure 3. NOAA–16 AVHRR imagery acquired on April 17, 2005 (12:10 UTC). The image is a composite of visible and IR channels (RGB: 1,2,4).

Figures 2–3 present the successive acquisitions of NOAA (17 and 16) AVHRR imagery on April 17, 2005 (09:10 and 12:10 UTC, respectively). These are false colour composites (RBG: 1,2,4) with dust appeared as a yellow-brown haze. This continuation of successive image acquisition permits to track the course of the dust plume and report the areas, which are mostly affected.

2.3 Description of meteorological situation

An intense Saharan Dust outbreak affected large part of Greece on April 17, 2005. Powerful winds pulled a thick band of Saharan desert dust over the Mediterranean Sea. African dust frequently blows over the Mediterranean in the spring, carrying tons of dust into Greece. This particular intense storm shrouded the country in a yellow/red haze (see Figure 4). The atmosphere was for hours suffocating, while the visibility had been limited in a few meters. As a result, flights were cancelled or delayed, sea transport was halted, while problems were even mentioned for car traffic.

Figure 4. Snapshots of Athens (left) and Crete (right) depicting the yellow/red haze resulting in low visibility.

This was due to following meteorological phenomena.

The presence of the barometric low-pressure system and the south-western winds existed in the low and intermediate layers of atmosphere, transferred grains of sand from northern Africa and concretely from the region of Libya. The nine (9) Beaufort winds in the Open Sea and the deep barometric low-pressure system in southern Ionian caused the transfer of dust above the Mediterranean Sea. The south winds caused “fogs of transport” from the marine regions covering almost the whole country, causing a “blurring effect” of atmosphere (yellow/red colour).

Moreover, thin cloudiness accompanied the barometric low. In certain regions were also mentioned weak rainfalls enriched with grains of sand. Finally, temperature was raised up to 26 degrees (Celsius) due to the hot transport from northern Africa to the Hellenic region.

The presence of dust is visible in the clouds from the "dull" colour, which was due to the scattering effect of solar radiation. This was due to the presence of the huge number of particles in the middle of atmosphere. The phenomenon was more intense in the southerners and the western regions, mainly in Attica, Peloponnese and Crete.

The concentration of grains of sand in the air above Athens Basin oscillated the 100 μgr/m^3. The mean concentration each spring, when this phenomenon often occurs, does not exceed the value of 10-15 μgr/m^3. In the cities of Peloponnese the highest concentrations reached and in some cases exceeded the 80 μgr/m^3, while in Crete it reached the value of 85 μgr/m^3.

3 Conclusions

In this paper we examined the potentiality of using various remotely sensed imagery for monitoring the evolution of an intense Saharan dust events on April 17, 2005. For this purpose successive NOAA-AVHRR images and AQUA MODIS imagery was used. Moreover, a description of the meteorological situation that led to this phenomenon was also discussed. In a further expansion of this research, the authors plan to implement more intense dust events introducing the available air pollution ground based measurements (i.e. PM_{10}) along with any other relevant remotely sensed imagery in order to fully understand the role of aerosols in a more local scale.

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