REMOTE SENSING AND GIS AS POLLUTION MODEL VALIDATION AND EMISSION ASSESSMENT TOOLS

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INTRODUCTION

Earth observation (EO) by very low spatial resolution satellite sensors (e.g., TOMS) has been a powerful addition to the array of techniques available for detecting and tracking atmospheric pollution on a global scale. Recently researchers are focusing on the use of EO to assess and map atmospheric pollution over and around cities, and a variety of techniques have been developed (*Holben, B. et al.*, 1992; *King, M.D. et al.*, 1999). Such techniques may be applicable to EO data with resolutions varying from low (e.g., Meteosat, AVHRR) to high (e.g., SPOT, Landsat) (*Vermote, E. et al.*, 1996; *Ignatov, A. and L. Stowe*, 2002; *Sifakis, N. et al.*, 1998; *Retalis, A. et al.*, 1999; *Wald, L. and J.M. Baleynaud*, 1999). High-resolution satellites allow mapping urban air-quality indicators such as the Aerosol Optical Thickness (AOT), which is indicative of the Particulate Matter (PM) loading in the atmosphere, particularly in photochemical pollution conditions (*Waggoner, A.P. et al.*, 1981).

This paper aims to present the potentiality of using remote sensing and GIS for monitoring air pollution and obtaining Atmospheric Optical Thickness maps in the lower troposphere, at regional scales, in the context of the GMES APMoSPHERE project (Air Pollution Modeling for Support to Policy on Health, Environment and Risk management in Europe). The APMoSPHERE project intends to demonstrate the potential and methods of linking different ground-based and satellite-derived data sets in Europe as a basis for air pollution and emission monitoring and mapping, with the aid of GIS, image processing and spatial statistical techniques.

INSTRUMENTATION AND DATA

In terms of satellite data, a series of MERIS level-2 full resolution (i.e., ground sampling distance of 300 m by 300 m) quarter scenes (300 km x 334 km) were selected, covering the period from May to August 2003 for the Greater Athens area, Greece. The acquisition time was around 12:00 p.m. local time and most of the images were cloud-free. In addition, a series of MODIS level-2 granule-based (granule: 5-minute segment of one orbit of data) images (10km x 10km pixel resolution) were acquired, covering the period from February to October 2003 for the Greater London area, UK. Moreover, all corresponding hourly ground-based measurements of PM_{10} concentrations were provided from the National Pollution Monitoring Networks of Greece and UK.

METHODOLOGY

The methodology implemented for the processing and analysis of MERIS images aimed at the reliable retrieval of AOT values as a surrogate to tropospheric aerosol loading values on an urban scale. Analysis of the data was initially performed for classifying the available images into highly, moderately and slightly polluted. Secondly, the selected MERIS images underwent geo-referencing in order to become geometrically coherent for proper interpretation. All images were geo-referenced according to UTM WGS 84 (zone 34N) projection system using the Ground Control Points (GCPs) included in the header file of each of the images with the use of BEAM software (*http://envisat.esa.int/services/beam/*). Subsequently, images were imported to ERDAS Imagine software in order to be processed for AOT retrieval over land in the metropolitan area of Athens (*ERDAS*, 2003). An appropriate cloud mask was also developed.

The Differential Textural Analysis (DTA) code based on the contrast reduction principle, was applied to the geo-referenced images in order to derive the spatial distribution of AOT over the Greater Athens area (*Sifakis, N. and P.Y. Deschamps*, 1992). This code follows a common basic procedure consisting in a radiometric comparison of multi-temporal satellite data sets of the same area acquired by the same sensor and geometrically corrected, during different pollution conditions, allowing to locate, to identify and to assess variations of the magnitude of optical atmospheric effects (OAE). The DTA algorithm was applied using a rolling window with size of 13 by 13 pixels. This window size was chosen on the basis of the structure function performance (*Paronis, D. and N. Sifakis*, 2003).

In the case of London area, AOT was derived from the MODIS aerosol properties reported in level 2 products at 10 x 10 km2. The MODIS aerosol optical thickness is derived with an error of $D\tau=\pm0.03\pm0.05\tau$ (*Chu, D.A. et al.*, 2002). Details of file specification of MODIS L2 aerosol products can be found at the Web site *http://modis-atmos.gsfc.nasa.gov*. A geometric correction was performed in MODIS images and an appropriate colour palette was used for categorisation of the AOT values and for better interpretation purposes.

Finally, the AOT values, retrieved precisely over the locations of the air quality monitoring stations in the areas of Athens and London, were used for validation through regression analysis to the PM_{10} concentrations measured at these stations.

RESULTS

Two AOT maps produced by MERIS products, using band 5, is presented in Fig. 1a and 1b, with "reference" image acquired on 15/06/2003. The obtained maps have a resolution of approximately 3.9km by 3.9km. Accordingly, an example of AOT map derived from MODIS data over London area is illustrated in Fig. 1c. It is obvious that the spatial resolution of the latter map is quite low.

The accuracy of AOT values extracted from MERIS and MODIS sensors was tested against PM_{10} measurements from the ground-based monitoring networks. Scatter plots indicating AOT values vs. PM_{10} for all the polluted days, for each study area, showed adequate correlation. It is noteworthy that in the case of Athens, the correlation coefficient is high (R^2=0.73) for the combination of the polluted images.

DISCUSSION

The high correlation found between retrieved AOT values and PM_{10} ground-based measurements indicates the potentiality of using Envisat MERIS and Terra MODIS observations for obtaining AOT maps over areas of regional scale. Moreover, this suggests that the application of the DTA algorithm on MERIS imagery, whenever available and cloud-free, could be used to provide accurate and reliable AOT maps at least for the Athens area.

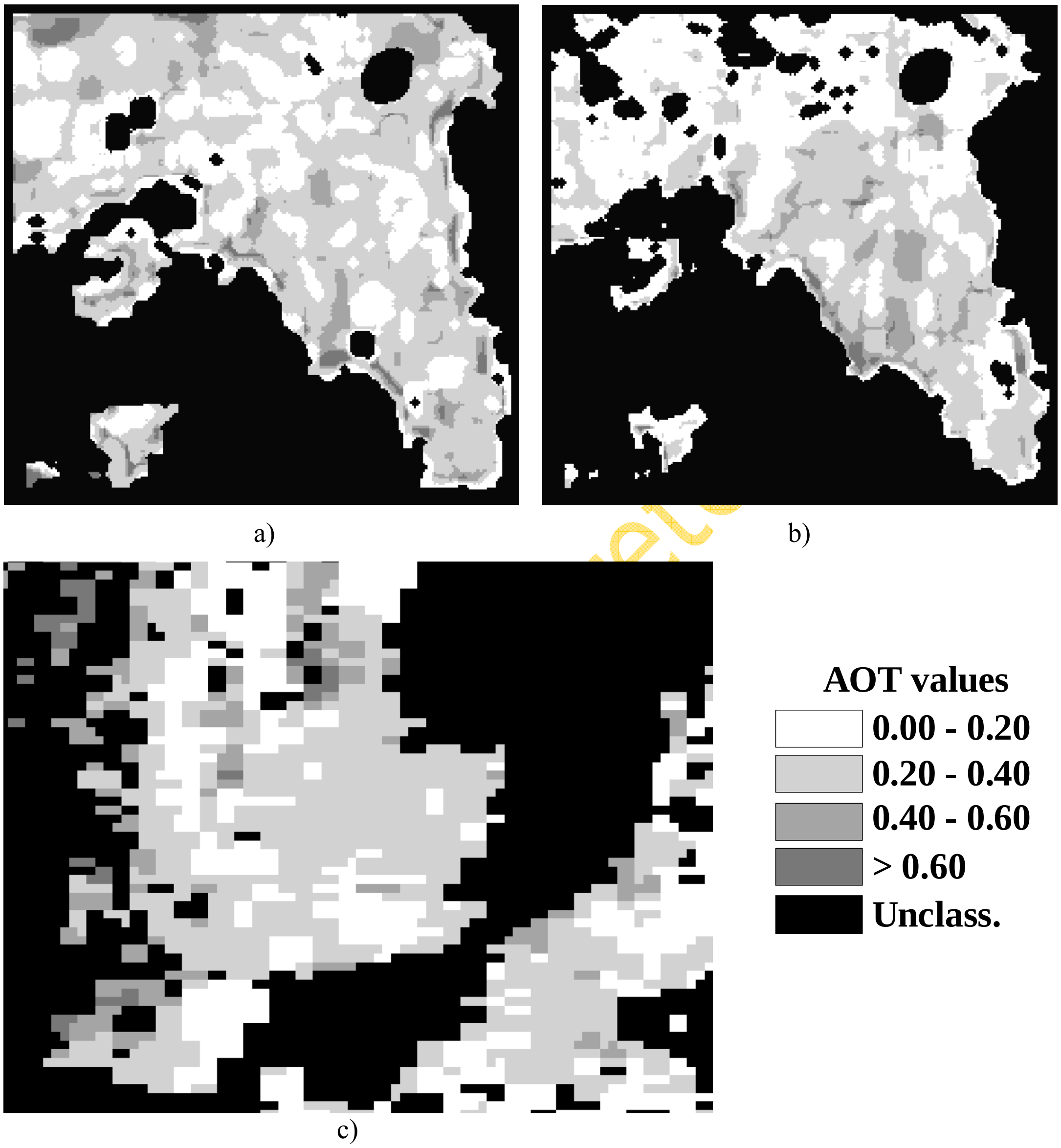

Fig. 1. Examples of extracted AOT maps over Athens area (a-b), using MERIS band-5 data and the "reference" image of 15/06/2003 and extracted AOT map over London area (c), using MODIS data.

However, the accuracy of the method is somehow limited by the moderate resolution of MERIS and MODIS data. This could possibly be alleviated by the synergistic use of high spatial resolution imagery (e.g., SPOT). Moreover, the method applied for MERIS image processing depends on the selection of a rigorously clean (from pollutants) and cloud-free image to be considered as the "reference" image.

Another limitation of the DTA algorithm is that, assuming a uniform particle size distribution and composition over the examined area, the type and amplitude of the OAE only depend on the atmospheric load of particles and can be expressed to AOT values. The assessment of OAE, and consequently of AOT, may also be influenced by variations over time of the underlying Earth surface.

Concerning the applicability in air pollution monitoring, it becomes clear that the technique applied in this paper will not replace the conventional analytical methods in measuring physical-chemical atmospheric parameters. It can provide, instead, overall spatial information that complements the analytical measuring methods and enhances their reliability. Subsequently, it is expected that an integrated method will be developed and applied in order to explore the possibility of linking satellite data with ground-based monitoring, and GIS-based techniques, as a basis for air pollution monitoring and mapping. Still, in order to set up the AOT map production on an operational basis, further work is expected on cross-validating the AOT extracted results with concurrent measurements from other EO sensors.

CONCLUSIONS

This study examines the potentiality of using MERIS and MODIS observations for obtaining AOT maps over Athens and London. Thanks to their short repeat period (only a few days) and their broad geographic coverage, these satellite sensors offer an especially powerful tool for air pollution mapping and potentially valuable means of stratifying and linking ground-based measurements. The high correlation found between retrieved AOT values and PM_{10} ground based measurements suggests that the application of the DTA code on MERIS imagery could be used to provide reliable AOT maps, indicating air quality information. However, the accuracy of the method is quite limited by the moderate resolution of the data, which means that the contemporaneous use of high spatial resolution imagery could lead to better results. Moreover, further work is expected in order to set up the AOT map production on an operational basis, as well as on further cross-validating the AOT extracted results with concurrent measurements.

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REFERENCES

Chu, D.A., Y.J. Kaufman, C. Ichoku, L.A. Remer, D. Tanré and B.N. Holben, 2002: Validation of MODIS aerosol optical depth retrieval over land. *Geophysical Research Letter*, **29**(12).

ERDAS, 2003: ERDAS Imagine 8.7 Field Guide, ERDAS Inc., Atlanta.

Holben, B., E. Vermote, Y. Kaufman, D. Tanré and V. Kalb, 1992: Aerosol retrieval overland from AVHRR data – application for atmospheric correction. *IEEE Transaction on Geoscience and Remote Sensing*, **30**, 212-222.

Ignatov, A. and L. Stowe, 2002: Aerosol retrievals from individual AVHRR channels. Part I: Retrieval algorithm and transition from Dave to 6S Radiative Transfer Model. *Journal of the Atmospheric Sciences*, **59**, 313-334.

King, M.D., Y.J. Kaufman, D. Tanré and T. Nakajima, 1999: Remote sensing of tropospheric aerosols from space: Past, present, and future. *Bulletin of the American Meteorological Society*, **80**, 2229-2259.

Paronis, D. and N. Sifakis, 2003: Satellite aerosol optical thickness retrieval over land with contrast reduction analysis using a variable window size. *IEEE International Geoscience & Remote Sensing Symposium (IGARSS)*, Proceedings in CD-ROM, Toulouse, France, 21-25 July 2003.

Retalis, A., C. Cartalis and E. Athanassiou, 1999: Assessment of the distribution of aerosols in the area of Athens with the use of Landsat TM. *International Journal of Remote Sensing*, **20**(5), 939-945.

Sifakis, N. and P.Y. Deschamps, 1992: Mapping of air pollution using SPOT satellite data. *Photogrammetric Engineering and Remote Sensing*, **58**, 1433-1437.

Sifakis, N., N. Soulakellis and D. Paronis, 1998: Quantitative mapping of air pollution density using Earth observations: a new processing method and application to an urban area. *International Journal of Remote Sensing*, **19**, 3289-3300.

Vermote, E., N. Saleous and B.N. Holben, 1996: Aerosol retrieval and atmospheric correction, *Advances in the use of NOAA AVHRR for land applications*, G. D'Souza, et al. Eds., Kluwer Academic Press, Dordrecht.

Waggoner, A.P., R.E. Weiss, N.C. Ahlquist, D.S. Covert, S. Will and R.J. Charlson, 1981: Optical characteristics of atmospheric aerosols. *Atmospheric Environment*, **15**, 1891-1909.

Wald, L. and J.M. Baleynaud, 1999: Observing air quality over the city of Nantes by means of Landsat thermal infrared data. *International Journal of Remote Sensing*, **5**, 947-959.