Satellite Image Processing for Haze and Aerosol Mapping (SIPHA): Code description and presentation of results

N. I. Sifakis[1], N. A. Soulakellis[2]
[1]Institute for Space Applications & Remote Sensing, National Observatory of Athens
Metaxa & Vas. Pavlou, Pendeli, GR-15236 Athens
Phone:+301-613.83.40/Fax:+301-613.83.43/Email:sifakis@space.noa.gr
[2]Department of Geography, University of the Aegean, Mytilini, Greece

ABSTRACT

The monitoring of aerosol concentrations becomes a high environmental priority particularly in urban areas. The aerosol optical thickness in the visible spectrum is a surrogate for fine aerosol concentrations, especially under pollution conditions with low mixing height, and can be measured with high ground sampling density with the help of satellite sensors. The SIPHA code was developed for such application on high-resolution satellite images and allows quantification of the aerosol optical thickness over land, snow and sea. The code compares multitemporal satellite data sets and evaluates radiometric alterations due to the optical atmospheric effects of aerosols. A novel feature of this code is the decoupling of the radiometric alterations due to optical atmospheric effects from those due to ground temporal variations. A real-scale application of the code on time series of Landsat data was carried out over European urban sites.

INTRODUCTION

Airborne particulate matter or aerosols, whether anthropogenic or of natural origin constitute a major environmental issue: At regional level, aerosols are contributors to visibility degradation (haze) and to acid deposition; at global level they play a role in climate change [1]. At local level, epidemiological studies indicate that small-sized aerosols are causal factors in mortality in urban areas [2]. Therefore monitoring aerosol concentrations becomes a high priority at a variety of geographical scales.

Information concerning the aerosols spatial and temporal distribution at a global scale is mainly obtained by reported emission data subsequently introduced to transport/trend models, or by using low resolution satellite data provided at 40km resolution by the TOMS sensor (on Earth Probe satellite) and at a 5-10km resolution by the recent MODIS sensor (on Terra satellite). At local and regional scales, apart from isolated point measurements, there is no well-established means to obtain information on the spatial and temporal pattern and trends of the aerosols [3]. Landsat, SPOT and IRS satellites allowing high spatial resolution (HSR) land and sea observations, do not address aerosol concentration measurements, yet the radiometric alterations of their data induced by the so-called optical atmospheric effects (OAE) of aerosols, allow estimating the surrogate optical thickness. The OAE of the aerosols are quantified by image processing algorithms, such as the SIPHA code, based on the radiative transfer in the atmosphere, and applied to satellite data acquired under pollution conditions differentiated with respect to reference (i.e., pollution-free) data.

BACKGROUND

The SIPHA code is applicable to HSR satellite imagery with the aim of extracting quantitative information on the aerosol optical thickness at the moment of the satellite passages over a certain area. The underlying principle of the code is described in the following.

Even when it looks limpid, the Earth's atmosphere affects the downwelling (towards the Earth) solar energy, as well as, the emitted or reflected upwelling (towards the satellite sensors) energy, geometrically and radiometrically. Geometric alterations due to the atmosphere are linked to refraction and can be neglected since satellite Earth observations are carried out in the "atmospheric windows", that is, spectral areas with minimum absorption. Radiometric alterations are due to emission, absorption, scattering and backscattering by both atmospheric gases and aerosols. The most important radiometric alterations on HSR satellite imagery are linked to the presence of high concentrations of atmospheric aerosols of a certain size. Aerosols are found in the atmosphere in three size ranges: (a) Very fine transitional Aitken nuclei (mainly from burning processes) smaller than 0.1µm, (b) fine particles in the accumulation mode (from coagulation of the previous or photochemical reactions) between 0.1 and a few µm and, (c) coarse particles (from erosion or mechanical processes) larger than a few µm [4]. According to Mie's law the radiometric alterations depend on the ratio: particle size to wavelength of the radiation (i.e., sensed by the satellite). In the visible and near infrared spectral domains covered by HSR sensors the optically efficient particles are those in the second size category. Their OAE on satellite radiometry will be detected by the code.

The four OAE that the SIPHA code considers are:

a) The "blurring effect" is present mainly in the visible and near infrared bands and is linked to the scattering and backscattering induced by the aerosols predominantly in short wavelengths. This degrades the image texture due to contrast reduction [5].

b) The "screening effect" is revealed mainly in visible wavelengths as an attenuation of the observed reflectance and a distortion of the spectral response patterns. This is due either to the presence of strong light absorbers (e.g., soot particles) or to very bright underlying Earth targets (e.g., snow).

c) The "opacity effect" appears the same as the screening effect but is engendered only in the thermal infrared. This results in a veiling of the images due to the attenuation of upwelling radiative temperature by particles [6].

d) The "dark target effect" is present over clear water in the infrared spectral bands and is due to the backscattered by particles radiation [7].

Considering a uniform particle size distribution and composition over the examined area, the type and amplitude of all previous OAE will depend on the atmospheric loading of the aerosols. OAE will also depend on the features of the underlying Earth surface, in case of temporal land cover variations. This potential source of error is overcome by a special feature of the code, that is the combined application of all previous OAE, which allows the decoupling of radiometric alterations due to optical atmospheric effects from those due to ground temporal variations.

The quantitative evaluation of the OAE is finally carried out in terms of aerosol optical thickness in the visible (also known as atmospheric turbidity) that is, the columnar integral from the ground to the satellite of the extinction coefficient k_{ext} expressing the interaction between the radiation and atmospheric particles. The magnitude of optical thickness is connected to the columnar concentration of the optically effective aerosols usually concentrated in the first two kilometres from the Earth's surface, especially under pollution conditions when the mixing height is low.

CODE DESCRIPTION

The SIPHA code (Fig.1) has been developed on the ERDAS-IMAGINE Model Maker and is the latest version of the codes DTA [8] and SMA [9]. It is applicable to Landsat TM two-image data sets composed by one "pollution image" (i.e., acquired under representative conditions) and one "reference image" (i.e., acquired under very clear atmosphere).

The code initially performs a geometric rectification and a calibration of the images aiming to render them radiometrically comparable. This includes transformation of the digital numbers (DN) to apparent radiance values (L^*) and subsequently to apparent reflectance (r^*). DN from the thermal infrared (6th band) are converted to radiative temperatures (T). Then the code carries out a precise radiometric comparison based on the evaluation of the described OAE.

The combination of more than one effect allows quantifying the optical thickness without being subject to misclassifications due to ground-reflectance temporal variations. More specifically, the code has three different approaches depending on whether the examined area is land, water or perpetual snow.

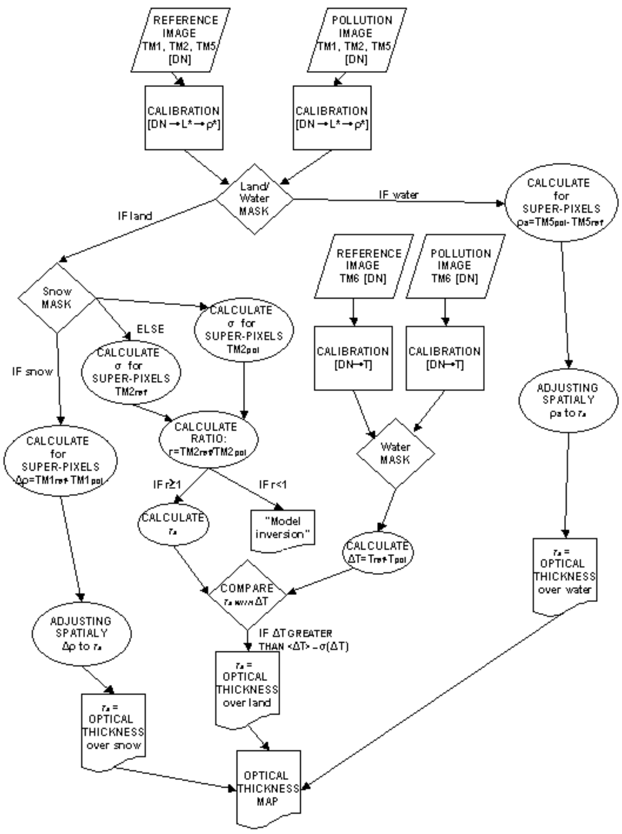

Figure 1. Flow chart of the SIPHA code.

In the case of land, the optical thickness is calculated on the basis of the "blurring effect", using the green spectral band, combined with the "opacity effect", using the thermal spectral band. The local analogical contrast is used as evaluator of the blurring. In the case of water, the calculation is based on the "dark target effect", using the infrared spectral band and the computed values are adjusted spatially according to adjacent values over land. Finally, in the case of snow, the calculation is based on the "screening effect" and the computed values are adjusted spatially according to values calculated over land.

APPLICATION

The code was tested on time series of Landsat TM data over two European sites renown for acute pollution: Athens (Greece) and Brescia (Northern Italy). The satellite data sets were selected so as to be representative for their pollution levels (i.e., recorded by the local monitoring networks), and with strict criteria for image quality and cloud cover especially for the image to be used as a reference.

The obtained "particulate-pollution maps" were examined in the light of ground truth data and transport simulation modelling according to emission data and meteorological information. In terms of spatial patterns the concentrations of both gaseous (sulphur dioxide, nitrogen oxides) and particulate pollutants (black smoke, PM10), as reported by local monitoring stations, were highly correlated with the optical thickness values [10]. In terms of temporal variation patterns the classification of the days according to the magnitude of the optical thickness corresponded to the pollution variations. Results finally showed that any increase in the aerosol concentrations in the atmosphere was detected, calculated in terms of optical thickness and mapped by the SIPHA code.

In conclusion the application indicated that the spatial coverage of satellite imagery combined with dynamic information of transport modelling and site-specific analytical measurements from few point measurements can provide an excellent alternative to fine aerosol concentration measurements.

ACKNOWLEDGMENTS

The European Commission funded part of this research under contracts No. 94/GR/A32/GR/ 01616/ATT and ENV4-CT97-0417.

REFERENCES

[1] European Environment Agency, Europe's Environment: The Dobris Assessment, Copenhagen, ed. D. Stanners and Ph. Bourdeau, 1995.

[2] A.C. Pope et al., "Particulate Air Pollution as a Predictor of Mortality in a Prospective Study for US Adults", American Journal of Resp. and Crit. Care Medicine, 151, pp. 669-674, 1995.

[3] S.R. Falke and R.B. Husar, "Maps of PM2.5 over the US derived from regional PM2.5 and surrogate visibility and PM10 monitoring data" in press.

[4] J. Colls, Air Pollution: An Introduction, pub. by E & FN Spon, 1997.

[5] D. Tanré, P.Y. Deschamps., C. Devaux and M. Herman, "Estimation of Saharan aerosol optical thickness from blurring effects in Thematic Mapper data". J. of Geoph. Res, 93, pp. 15955-15964, 1988.

[6] N. Sifakis, P. Bildgen and J.P. Gilg, "Utilisation du canal 6 (thermique) de Thematic Mapper pour la localisation de nuages de pollution atmosphérique - Application à la région d´Athènes (Grèce)", Pollution atmosphérique, 133, pp. 96-106, 1992.

[7] M. Griggs, "Measurement of atmospheric optical thickness over water using ERTS-1 data", J. Air Poll. & Control Ass., 25, pp. 622-626, 1975.

[8] N. Sifakis and P.Y. Deschamps, "Mapping of air pollution using SPOT satellite data", Photogrammetric Engineering & Remote Sensing, vol. 58, pp. 1433-1437, October 1992.

[9] N. Sifakis, N. Soulakellis and D. Paronis, "Quantitative mapping of air pollution density using EO a new processing method and application to an urban area", Int. J. of Remote Sensing, vol. 19, pp.3289-3300, November 1998.

[10] Sarigiannis D. et al., "ICAROS statistical models: Correlation of satellite-derived optical thickness with ground measurements of air pollutants concentration" unpublished.