Tracking The Toxic Time Bomb

Today's precision weapons may seem smarter and cleaner than their predecessors. Yet the environmental consequences of their deployment can be just as devastating. Nicolas Sifakis, Haris Kontoes and Panagiotis Elias describe how new techniques in satellite image processing bring greater clarity to a murky subject...

"A series of detonations that shook the whole city early yesterday sent a toxic cloud of smoke and gas hundreds of feet into the night sky. In the dawn the choking cloud could be seen spreading over the entire northern skyline." (*The Times, London, 19 April*). Eye witness accounts of the NATO air strike against the Serbian industrial complex of Pancevo alerted the world to a threat that has no respect for national boundaries and whose speed, direction and concentration is at the mercy of the elements.

Three strikes hit Pancevo early that morning, crippling a combined petrochemical and fertiliser plant and releasing a cocktail of chemicals into the air. Phosgene, chlorine and hydrochloric acid were among the noxious substances that greeted residents of the capital, some 12 km distant, as they emerged from their shelters following the all-clear. Yet this was not the only consequence of the strike. Workers at the plant decided to release tons of ethylene dichloride, a carcinogen, into the Danube in order to lessen the risk of explosion. Finally, oil and petrol from the damaged refinery was released into the river, forming a slick up to 20 km in length.

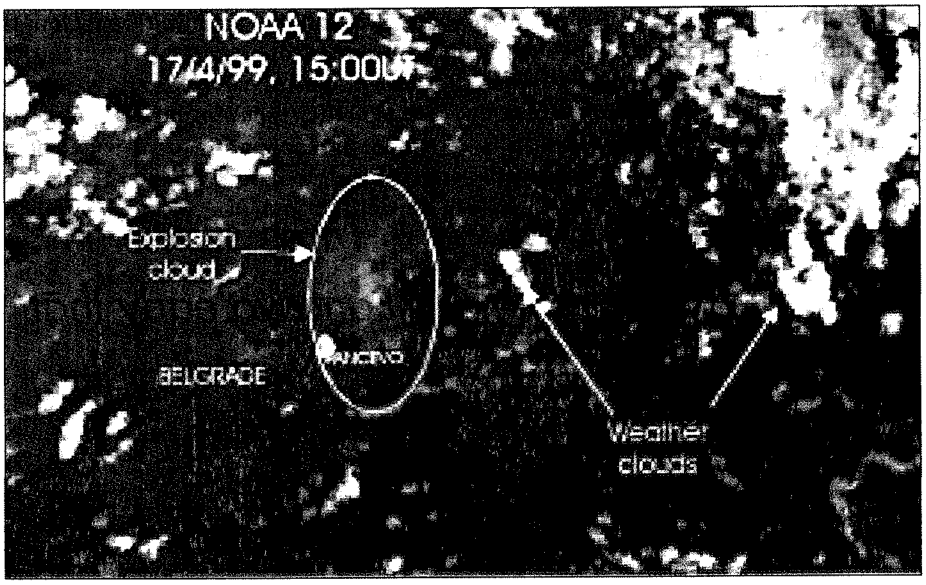

Fig. 1: Information from distinct spectral areas are combined in this false colour composite.

State of alert

With the scale of the pollution becoming increasingly apparent from imagery gathered by NOAA meteorological satellites, measuring networks in neighbouring countries were placed in a state of high alert.

In Greece, the Institute for Space Applications and Earth Observation at the National Observatory of Athens (NOA) acquires, calibrates and georeferences satellite imagery and then processes it for specific uses in urban monitoring, environmental protection, regional planning, agricultural Management and many other applications. With the Pancevo air strike threatening an ecological disaster, the Institute and a mobile measuring unit moved into top gear, acquiring low resolution NOAA data via their own antennae and supplementing these with high resolution imagery supplied through commercial channels.

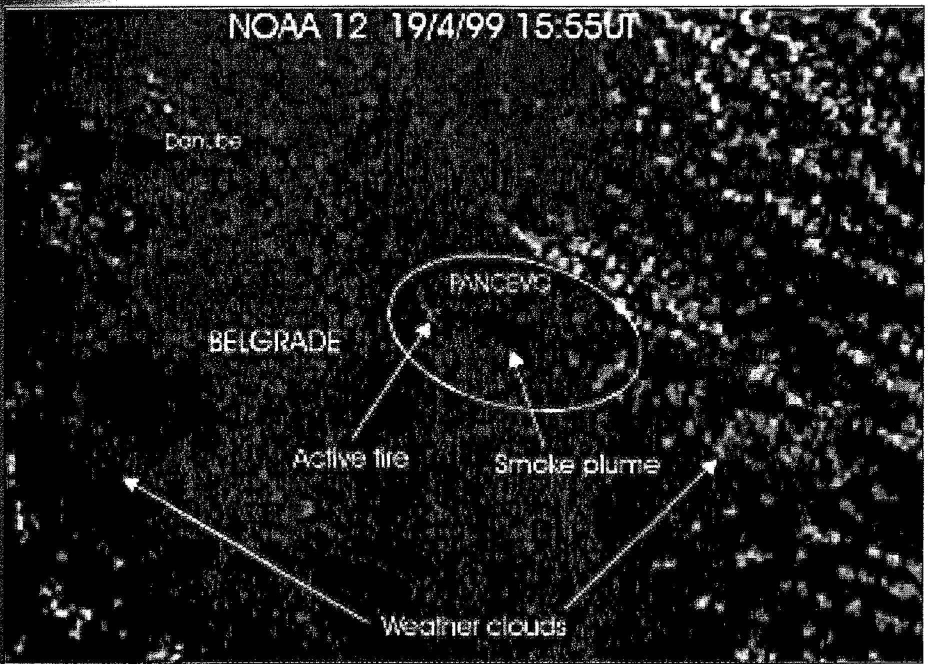

Fig. 2: Smoke plume drifts south east

Objective view

Examining the effect of the strike from a height of 800 km gave us an objective view of the overall situation and the risk it entailed. In addition to the synoptic picture they reveal, satellite sensors offer a more synthetic view since, in spectral terms, they can 'see' much more than the human eye. This improved our understanding of the local and regional effect of the bombing.

The Advanced Very High Resolution Radiometer on board the NOAA satellites has a moderate resolution of 1.1 km at nadir and five spectral bands in the visible, near infrared, middle infrared and two areas of the thermal infrared respectively. The two first spectral areas (visible and near infrared) represent reflected energy from the Earth and the atmosphere. In each of these bands, both weather and pollution/emission clouds appear very bright, although less so in the infrared - almost as in standard photographs.

The only exception is dense smoke emitted by burning oil or carbon. This thermal energy is released from the surface of the Earth and is eventually blocked by the presence of clouds. Here, thermal infrared imagery depicts cloud as colder and, hence, darker than their surroundings. Finally, the middle infrared wavelength bands record high temperature thermal phenomena and allow us to detect the focal points of fires or explosions.

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Localising the toxic cloud

Upon analysing the NOAA imagery, it became apparent that continuous air strikes had turned an extended region into a dense cloud of smoke, making it difficult to isolate local plumes. Nonetheless, on the satellite images of April 17, during, the bombing of Pancevo, the explosion cloud could be clearly observed. A closer inspection of the image recorded at 15:00 UT on the same day revealed a distinctly visible white cloud spreading around the industrial complex. .

The false colour composite (Fig. 1) combines information from three distinct spectral areas to show (a) the visible energy reflected by the explosion and cloud, (b) the high temperature infrared energy emitted by the explosion and (c) the low temperature infrared energy absorbed by the cloud.

Two 'optical effects' helped distinguish this pollution cloud from weather clouds:.First, the high temperature released during the explosion and, second, a blur that occurred in the visible spectral channel and which was characteristic of small-sized particles (unlike the large water droplets of meteorological clouds). The first effect was due to very high temperatures in the blazing plant (said to have reached 1000∫ C). The second is explained by the fact that weather clouds are highly reflective and totally opaque, while haze and smoke plumes are highly reflective or absorbent respectively. This gives an indistinct and semi-opaque shape to land features observed by the satellite.

Two days later, at 15:55 UT, the colour composite derived from NOAA-12 showed a distinct smoke plume, probably emanating from an active oil fire . This plume drifted East-Southeast and remained clearly visible over a distance of some 50 km. The smoke cloud (Figs. 2 and 3) appears black, signifying high concentrations of highly absorbent particles (e.g., elemental carbon) and a moderate temperatures.

Finally, on April 20 at 18:17 UT a grey-scale infrared image from NOAA-15 revealed no fresh emission of smoke; only some limited fires still active inside the complex (Fig. 4).

Higher resolution Landsat, SPOT and IRS satellite data are currently being collected and examined to add more spatially detailed information to the picture.

Air-pollution mapping by satellite

The work undertaken by NOA arises from its interest in monitoring aerosol pollution, following widespread concern as to health risks of small-sized airborne particles. Since no satellite instrument in orbit directly measures air pollution in the boundary layer (lowest part of the atmosphere) there is, as yet, no means to obtain reliable spatial information as to the distribution of these pollutants:

High *spatial* resolution satellite instruments are unable to derive air pollutant-specific information as this requires high *spectral* resolution. The two are incompatible. Low spatial resolution satellite instruments can perform specific gas measurements, but only in the higher atmosphere which, of course, is of little relevance to areas of population.

Future satellite sensors such as SAGE III and MIPAS will provide very coarse resolution data in lower parts of the atmosphere, and TES and SCIAMACHY will peer with improved spatial resolution, but not down to the boundary layer.

Filling the gap

To compensate for this information gap, and pending future active systems such as ATLID (with enhanced atmospheric measuring capabilities), the NOA has developed methods that utilise existing data to yield reliable and quantifiable indicators of air pollution.

One such indicator is that of atmospheric turbidity (or aerosol optical thickness in the visible). This indicates overall particulate pollution levels and can be extracted over urban areas by comparing multi-temporal Earth Observation (EO) satellite data. New techniques and software routines developed by NOA allow us to quantify air pollution over urban areas under varying atmospheric conditions.

For example, the SMA (Satellite Mapping of Aerosols) routine compares satellite images and evaluates the radiometric anomalies encountered in different spectral bands. Such anomalies include a distortion of the spectral response pattern or 'blurring' in short (visible) wavelengths; enhanced reflectance in medium (near infrared) wavelengths, and a veiling of the images (increased opacity) in longer (thermal infrared) wavelengths.

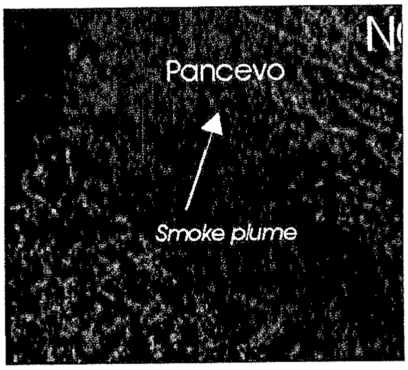

Fig. 4: No new smoke, and only limited activity inside the complex

Modern phenomenon

The urban area to which these methods and routines were initially applied for testing was Athens, a city renowned for its air pollution. The phenomenon in the Greek capital is known as 'the nephos' (the cloud), a name that aptly describes its characteristics: reduced visibility due to high concentrations of aerosol particles and a yellowish-brown hue caused by a build-up of nitrogen dioxide. Landsat-5 satellite data sets were selected on the basis of pollution levels recorded by the local monitoring network and employing standard criteria for image quality and cloud cover. This was the first exercise of its type to be undertaken in the capital.

Satellite pollution maps offer a general view of how a pollution plume spreads under various meteorological conditions and, in combination with dispersion modelling, help explain the spatial distribution of aerosol concentrations at single points in time. The extracted optical thickness values allow diachronic comparisons over different seasons/years in urban or industrial regions. This would suggest that EO imagery could be utilised as a decision support tool for regional air pollution abatement. It could, for example, be used to optimise the siting of pollution monitoring stations or strengthen the link between analytical point measurement and simulated dispersion modelling. Not least, such applications would enhance the value of archived historical satellite data. G

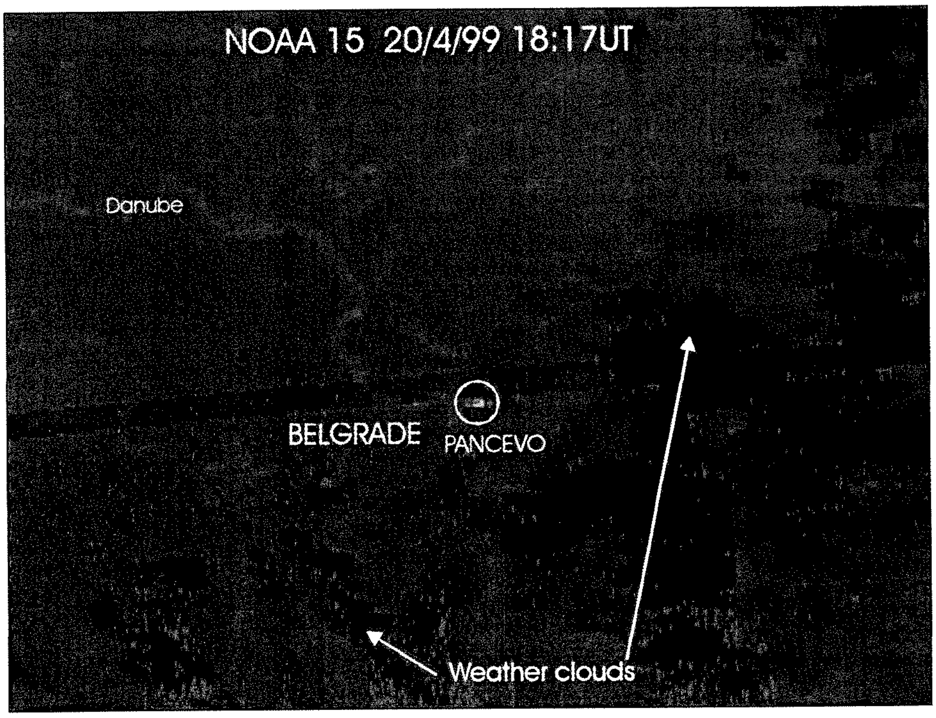

Fig. 3: Black plume signifies high levels of absorbent carbons

__NICOLAS SIFAKIS__ is a research scientist at the NOA, Athens, and an advisor to the European Environment Agency. He was project manager of the European CORINE Land Cover project from 1991 to 1994. __HARIS KONTOES__ is a research scientist at the Institute for Space Research and Earth Observation, NOA, Athens, and executive secretary of the Hellenic Space Research and Technology Committee. __PANAGIOTIS ELIAS__ is also with the NOA and works as technical assistant in the Institute of Ionospheric and Space Research.