SATELLITE DETECTION OF SMOKE PLUMES AND INADVERTANT WEATHER MODIFICATION

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ABSTRACT

Satellite imagery provides a convenient and inexpensive means for monitoring smoke plumes and evaluating inadvertant weather modification. Visual examination of LANDSAT-1 imagery for two sites in east-central Ohio indicates that, at times, a plume may extend nearly 48 km downwind and reach a width of six km. Density slicing techniques provide clues as to the particulate loading in a plume.

The areal extent of plumes can be mapped and could be studied for adequate siting of ground stations in order to monitor the chemical quality of precipitation and evaluate the effects on the ecosystem.

Several satellite images show unusual cloud structures that occur in the vicinity of industrial sites. It is suspected that particulates and gases from the many stacks are related to the origin of the unusual cloud formations. A dense water vapor cloud originating at a large cooling tower is clearly visible on one image. About 20 km downwind, the snow belts spread out forming a snow field about 20 km long and 20 km wide. It is suspected that the water vapor released at the cooling tower is responsible for the large downwind snowfall.

INTRODUCTION

From the ground or even aircraft it is difficult to visualize or map the areal extent of smoke plumes or detect areas of possible inadvertant weather modification. Without an accurate mapping capability it frequently proves difficult to determine the average or maximum areal extent of smoke or vapor plumes thus adding to the problem of adequately locating ground stations to evaluate the effect of atmospheric pollutants on the forest or some other ecosystem.

Preliminary studies indicate that satellite data can be useful for the regional study of smoke plume dispersion, inadvertant weather modification detection, and provide several other potentially important bits of information. Satellite data are available on a repetitive basis (minimum of 9 days), require no sophisticated instrumentation for many types of analysis, and are very inexpensive. The imagery used in this study was obtained from the first Earth Resources Technology Satellite (ERTS-1), which is now known as LANDSAT-1*.

LANDSAT-1 was launched on 23 July 1972 and stabilized in a near polar orbit about 900 km above the earth. The satellite contains two remote sensors, a multi-spectral scanner (MSS), which records reflected visible and near infrared radiation in four spectral bands (4,5,6, and 7), and a return beam vidicon camera (RBV). The satellite's synchronous orbit allows fourteen orbits each day and coverage of the same area every eighteen days at the same local solar time, which is approximately 0942 hours at the equator.

The RBV system became inoperable shortly after launch therefore most of the satellite investigations have been based on the MSS. The MSS scans an area 185 km wide providing continuous coverage along each orbital track. Pictoral images are framed at Goddard Space Flight Center, Maryland with 10% forward and at least 14% sidelap between images. Each frame covers about 34,200 km^2; spatial resolution for the images averages about 80 meters.

Previous work with LANDSAT-1 and air pollution or weather modification includes recent studies by: 1) Lyons and Pease (1973), and Lyons (1974) to detect smoke plumes over Lake Michigan, 2) Griggs (1974) to measure atmospheric aerosol content over San Diego and the Salton Sea, 3) Kahan (1974) to use the satellite data collection system to monitor weather conditions for cloud seeding operations in the Colorado River basin, and 4) Murtha (1974) to study SO_2 damage to a forest in Ottawa.

SMOKE PLUME DETECTION

In view of the recent emphasis on air pollution control by the Ohio Environmental Protection Agency, a cursory examination of several LANDSAT-1 scenes was carried out in an attempt to evaluate their usefulness for monitoring smoke plumes. Enlarged prints (20 × 20 cm) were made from several 70 mm negatives representing different intervals of time. Originally no sophisticated techniques, such as density slicing, or color enhancement, were used; the images were evaluated only by a

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*Imagery is available to the public; write: United Sates Department of Interior, EROS Data Center, Sioux Fall, S. Dak., 57198.

magnifying glass or by the unaided eye. Photographic prints were enlarged to a convenient scale (approximately 1:500,000). The areal extent of visible smoke plumes, as best seen on the green and red bands (4 and 5, respectively) was recorded on a base map.

The major areas of interest included two sites on the Muskingum River in southeastern Ohio, and an industrial complex along the Mahoning River in the vicinity of Youngstown, in northeastern Ohio.

The areas examined along the Muskingum River lie in the vicinity of Philo and Beverly. In the Philo area are at least two major smoke producing industries. These include a ferro-alloy plant and an adjacent coal-burning electric generating plant. Satellite data clearly indicate that the ferro-alloy plant produces, by far, the greatest amount of smoke (Figure 1).

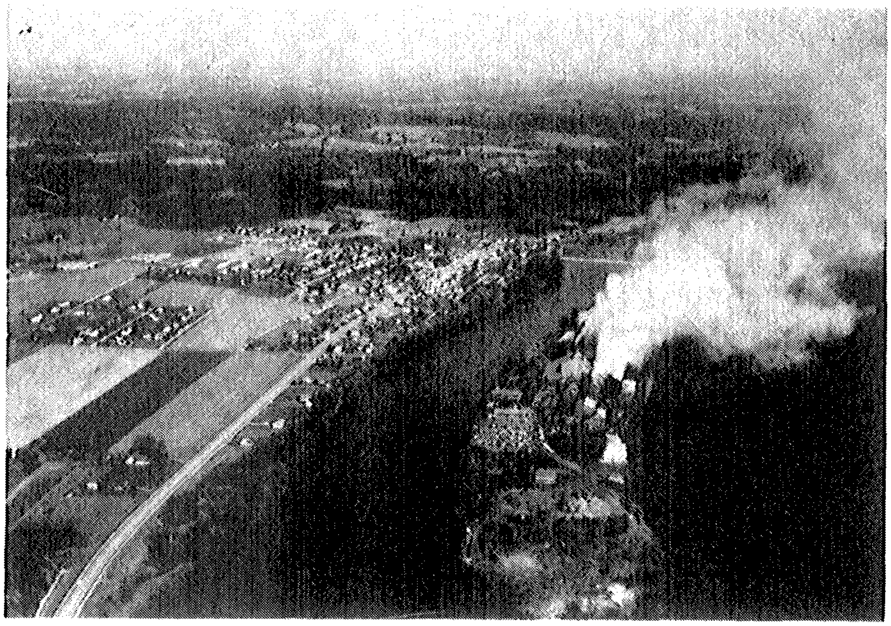

Figure 1. Ferro-alloy plant near Philo, Ohio (Site A).

The generating plant in the vicinity of Beverly (Site B) has a capacity of about 1530 megawatts and consumed 4192.4 thousand tons of coal in 1971. The coal had an average sulphur content of 4.9% and averaged 20% ash. The plant also consumed 46.7 thousand barrels of oil. During the same year the power plant at Philo (Site A), which has a capacity of 500 megawatts, consumed nearly 959 thousand tons of coal with an average sulphur and ash contents of 3.9% and 16.8% respectively. This plant required 12.5 thousand barrels of oil. These data indicate that the plant at Beverly consumed more than 4.5 times as much coal and

and 3.7 times as much oil as the Philo plant (Figure 2). Unfortunately recent fuel consumption records are not available.

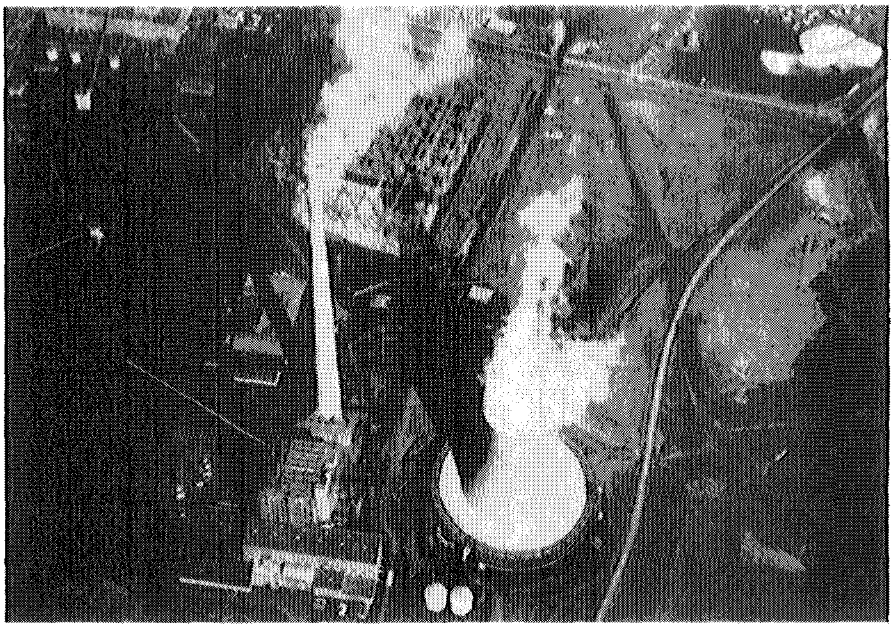

Figure 2. Coal-burning electric generating plant near Beverly, Ohio (Site B).

A partial satellite scene of the two smoke producing areas is shown in Figure 3. At Philo (Site A) and near Beverly (Site B), smoke was evident on seven LANDSAT-1 scenes, not evident on four scenes, and obscured by clouds on the other four scenes examined (Table I). The density and directional trend of the plumes are controlled by local atmospheric conditions. Wind direction, velocity and atmospheric mixing play dominant roles. As indicated in Figure 4, the plumes range from short, high-density to large, low-density features. The plume originating at the Beverly plant is most often the largest and may exceed 32 km in length. On 30 July, 1973, however, the Philo plume extended northward about 48 km nearly to Coshocton and reached a width of 6 km. Although severely limited in number, available imagery seems to indicate that the major direction of plume movement from both sites is generally southward, ranging laterally from 90° to 270°. Circles with centers at Philo and Beverly with a radius of 40 km would most likely enclose the major region of plume influence. The plumes commonly flow a few hundred meters above the ground.

If the images were examined by more sophisticated techniques, in particular density slicing, it is quite certain that the areal extent of

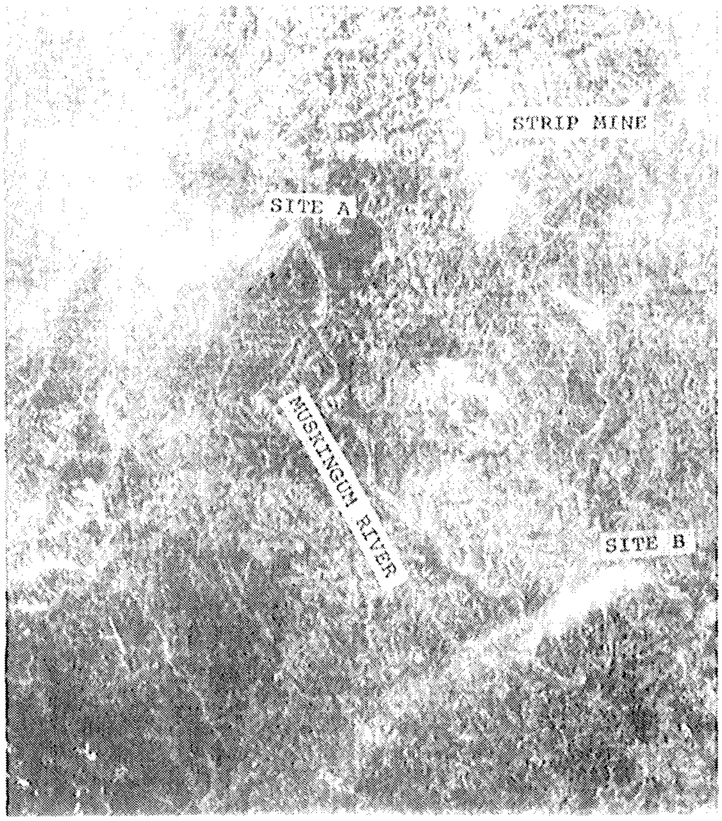

Figure 3. Partial LANDSAT-1 scene showing smoke plumes, trending southwest, originating at Philo (Site A) and Beverly (Site B) (Scene No. 1408-15410 04Sep73, band 5). Bottom edge of photograph is approximately 50 km.

the plumes could be more accurately mapped. Although it is a relatively simple process to map smoke plumes directly from LANDSAT-1 imagery, we do not know exactly what concentrations of particulate or gaseous matter the visible plumes represent. In order to be a truly viable monitoring technique, it would be necessary to determine, directly from the imagery, the total suspended particulate mass loadings and size concentrations in the plumes. Very likely this can be accomplished by aircraft, instrumented with sensitive air pollution and meteorological sensors, flying through the plumes during LANDSAT-1 overpasses. The measured concentrations could then be compared with differences in spectral response evident on the imagery.

Figure 5 shows computer processed, density sliced, imagery of the smoke plumes at Philo and Beverly. The different shades of gray indicate differences in particulate loading of the smoke plumes. The

TABLE I

Visability of smoke at Philo (Site A) and Beverly (Site B), Ohio, satellite scene number and date of overpass.

LANDSAT-1 Scene Number	Date	SMOKE PLUME Evident	SMOKE PLUME Not Evident	Site cloud Covered
1029-15361	21 Aug. 72	x		
1048-15414	09 Sep. 72	x		
1173-15362	12 Jan. 73	x	1	
1192-15422	31 Jan. 73			x
1210-15423	18 Feb. 73		x	
1228-15424	08 Mar. 73	x		
1264-15425	13 Apr. 73			x
1299-15365	18 May 73		x, 2	
1299-15363	05 Jun. 73		x, 2	
1372-15414	30 Jul. 73	x		
1407-15352	03 Sep. 73	x, 3	2	
1408-15410	04 Sep. 73	x		
1425-15350	21 Sep. 73		2	x
1444-15401	10 Oct. 73			x
1461-15340	27 Oct. 73		x, 2	

1. Site A not on image
2. Site B not on image
3. Extent of plume too small to be shown in Figure 4.

illustration merely shows what might be done by means of density slicing techniques.

Smoke plumes, per se, are not evident on any of the imagery examined of the Youngstown area. There is visible on the 12 January and 21 September, 1973, imagery, however, what appears to be a very interesting, seldom recognized, phenomenon. Long narrow clouds originate at several sites just south of the Mahoning River but downwind of the Youngstown industrial complex (Figure 6). As these clouds are traced northeastward (downwind) they become significantly larger while the clouds on either side of them remain about the same size. It is strongly suspected that this is caused by particulate matter originating upwind at 10 or 12 individual stacks. Similar features have been described for the Gary-Chicago area by Lyons and Pease (1973).

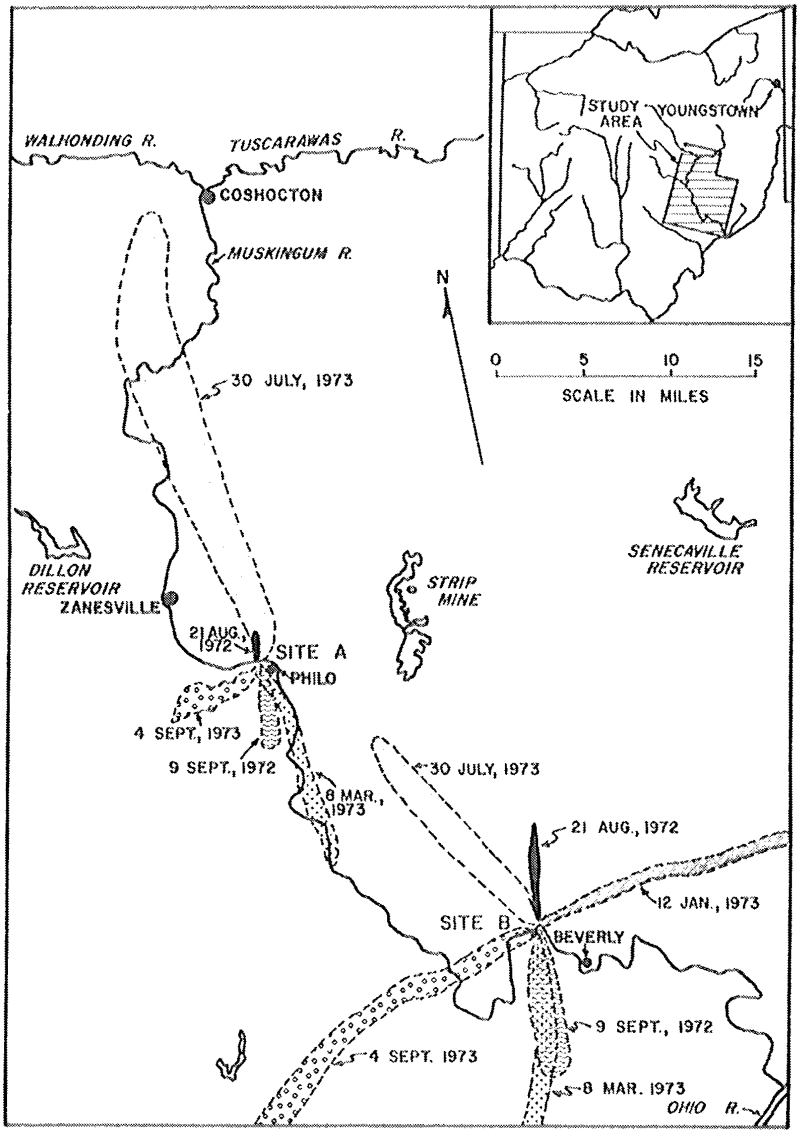

Figure 4. Map based on LANDSAT-1 data showing areal extent of smoke plumes originating at Philo and Beverly.

INADVERTANT WEATHER MODIFICATION

Several interesting phenomena are shown on a partial LANDSAT-1 scene acquired on 12 January 1973 (Figure 7). The area covered by this image includes a part of east-central Ohio and adjacent parts and western West Virginia. The Ohio River nearly bisects the scene; an abundance of clouds appear in the eastern part of the image with their long

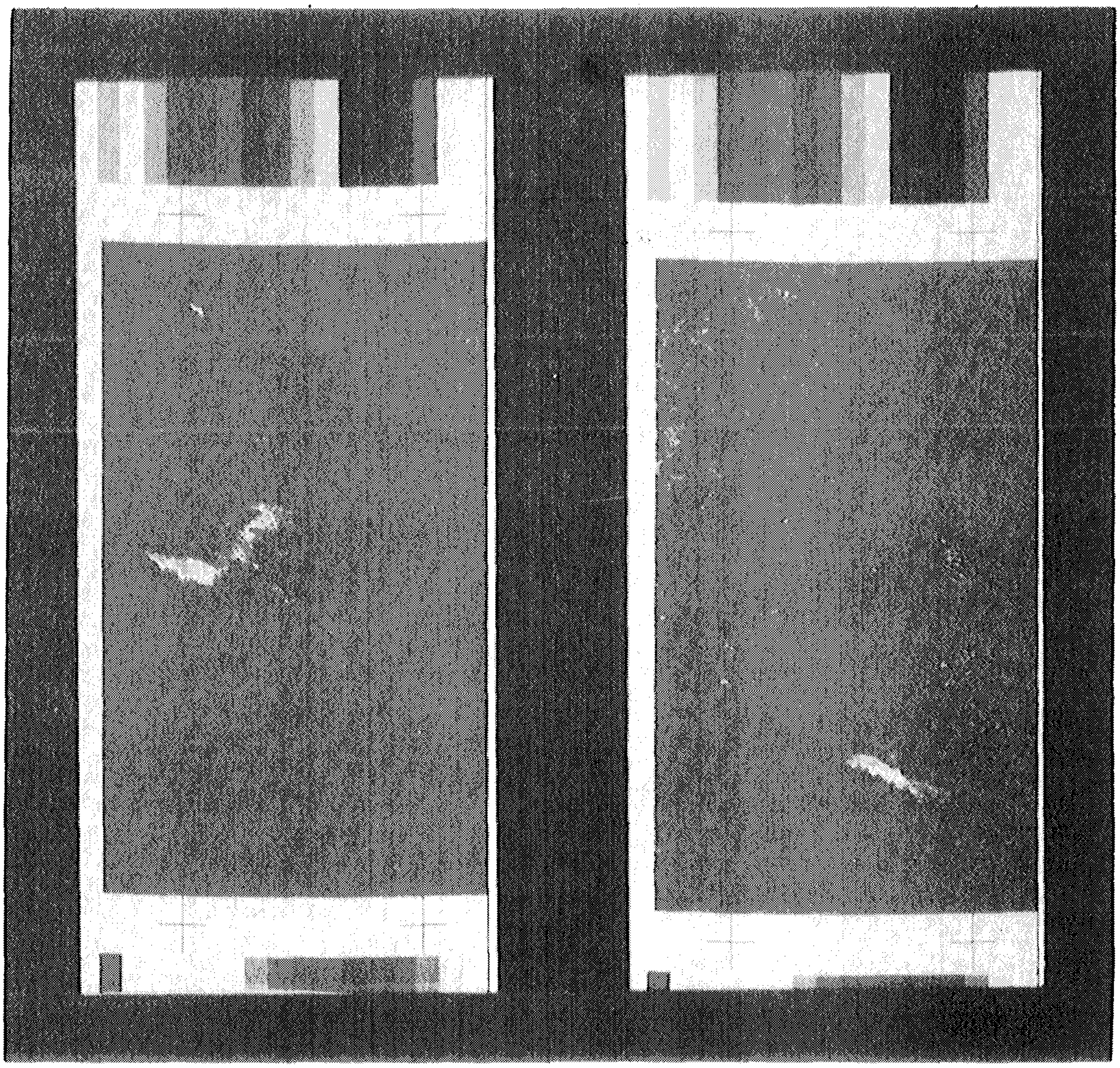

Figure 5. Density sliced smoke plumes at Philo (left) and Beverly (right) produced from satellite imagery. This is a contact print of a color transparency; the darker tones indicate the densest smoke. Bottom edge is approximately 48 km.

axis trending northeast-southwest. The light area in the northwest part of the image represents a thin cover of snow on the ground. The light bands extending diagonally represent trails of snow, which fell probably only a few hours before the image was taken. The snow clouds were moving southeast; the wind direction at the time of satellite overpass was blowing to the east as indicated by the plumes at Sites A, C and D, as well as several other plumes which are not marked. Site A is the location of a large cooling tower at an electric generating plant. The large white cloud that originates at Site A is caused by condensing water vapor discharged from the cooling tower. Notice that about 20 km

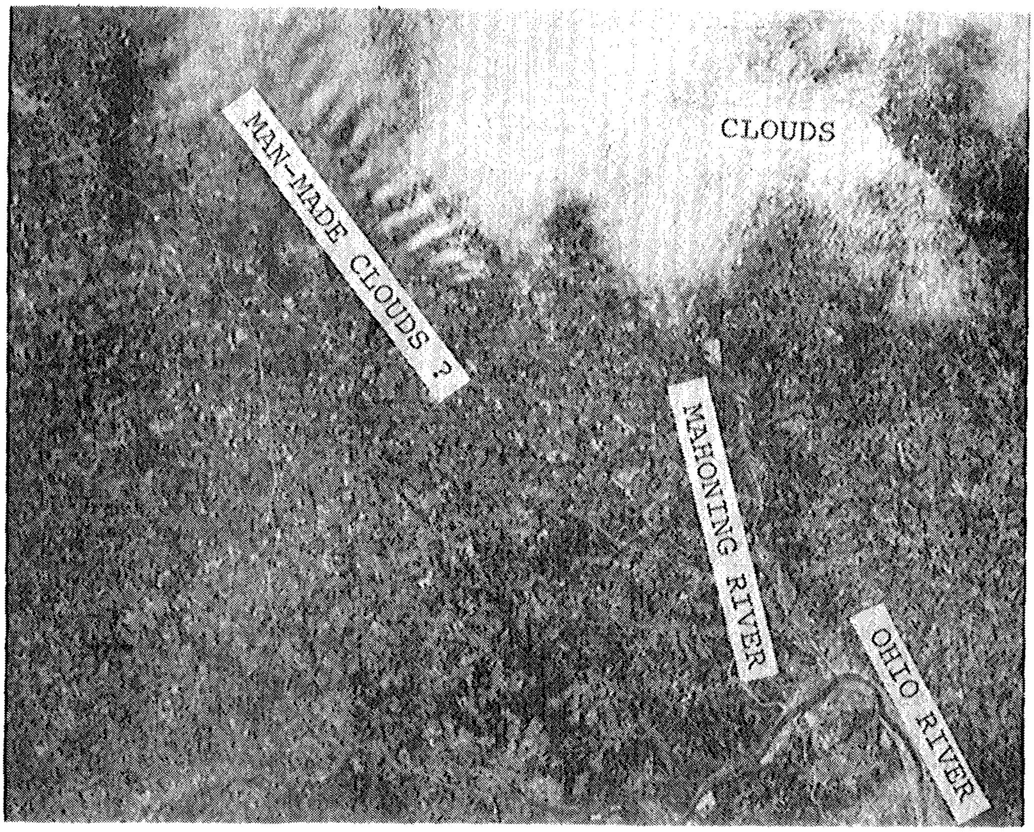

Figure 6. Partial LANDSAT-1 scene of the Warren-Youngstown, Ohio area showing man-modified clouds (?) originating in the vicinity of major industrial sites along the Mahoning River (Scene No. 1425-15350, 21Sep73, band 5). Bottom edge of the photograph represents approximately 80 km.

east of Site A is a large area where snow covers the ground (Site B). It is assumed that this larger area of snowfall reflects inadvertant weather modification caused by the high concentration of water vapor generated at the cooling tower.

The clouds in the vicinity of Site C appear to be less dense and larger than those in surrounding areas. This is also the location of a cooling tower, which is evident because of the condensation of the water vapor. It is suspected that the large quantity of water vapor and heat released at the cooling tower is directly related to the differences in the apparent density of the clouds. Similar features of different locations are evident on other satellite scenes.

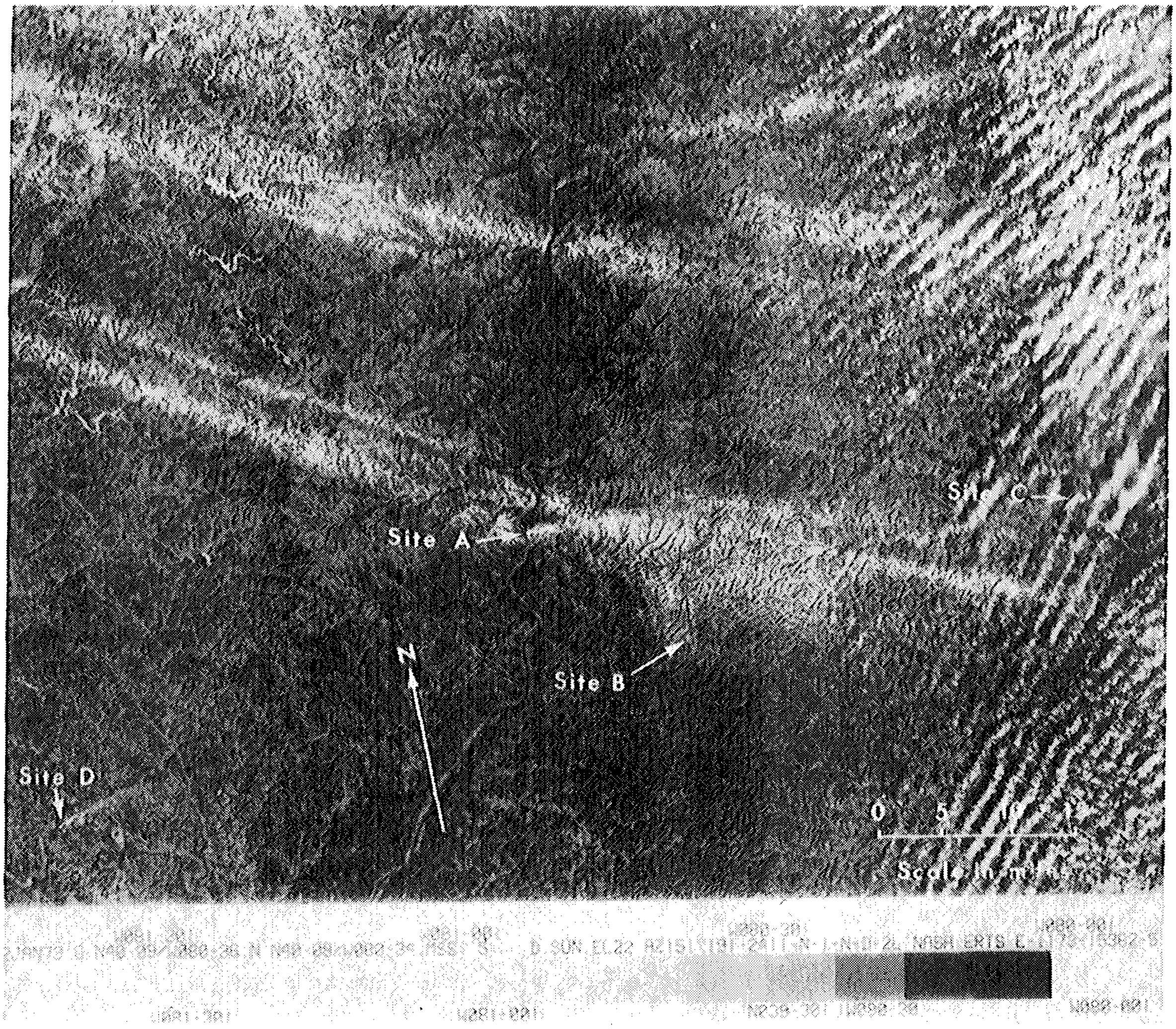

Figure 7. Partial LANDSAT-1 scene of eastern Ohio and western West Virginia showing snow belts, cooling towers and large area of snow caused by cooling tower vapor (Scene No. 1173-15362, 12Jan73, band 5).

SUMMARY

It is a well known fact that air pollution not only decreases visability but that it may also have a profound effect on the quality of rainfall thus increasing ecologic stress. This is exemplified by the decreasing pH rain that is related to the increasing concentration of atmospheric gaseous contaminants, such as sulfur and nitrogen oxides, released by the burning of high sulfur fuels. Although acid rainfall is not of immediate danger to humans, it does considerable damage to man-made structures and has serious implications for ecologic systems.

It is quite evident that satellite imagery can be used to examine and map the areal extent of smoke plumes and indicate areas of inadvertant weather modification. They can also be used to determine areas where ground surveys could be conducted in order to evaluate the effects of air pollution on vegetation.

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