# PLUME TRAJECTORIES USING SATELLITE IMAGERY

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The feasibility of using high resolution satellite imagery as an aid to defining the transport of particulate air pollution plumes and the determination of turbidities for widespread haze layers is discussed. Limitations of the technique are also noted.

Recent work has demonstrated the usefulness of satellite imagery for the detection of particulate air pollution plumes.[44,45,46,47] In particular, the Landsat satellites have been providing high resolution, multi-spectral images of various portions of the earth's surface since late 1972. These satellites orbit the earth sun-synchronously at an altitude of ∿1000 km, making 14 revolutions of the earth each day with crossings of the equator at 0942 hr local time. Every 18 days, a given satellite roughly repeats its traverse over a given area. The images, providing resolution detail to 100-200 m, cover a square surface area roughly 185 km by 185 km.

This report describes efforts to assess the feasibility of using high resolution satellite imagery as an aid to defining the transport of power plant particulates in the atmosphere and to take advantage of the digital image processing expertise available at Pacific Northwest Laboratory (PNL). This study was intended to support Multi-State Atmospheric Power Production Pollution Study (MAP3S) field programs in the Northeast.

Microfilm images taken by Landsats I and II over Lake Michigan were scanned to select those images showing some type of plume development. One image for lower Lake Michigan taken on 10 June 1973 (Image ID 1322-16045) was selected for detailed analysis with a variety of computer enhancement techniques. A black-and-white composite, made up of images from the four multi-spectral scanner (MSS) bands (0.5-0.6 μm, 0.6-0.7 μm, 0.7-0.8 μm, and 0.8-1.1 μm), is shown in Figure 1.28. Individual plumes originating from the shoreline are easily discernible out to 50-100 km, where they merge into an overall haze. There is also evidence in this photo of albedo vari-

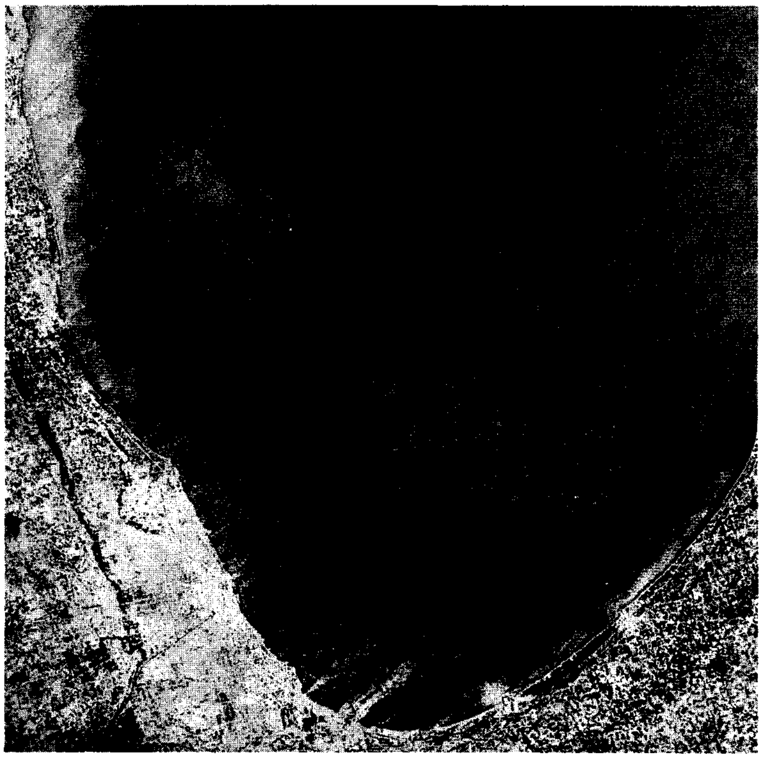

**FIGURE 1.28.** Black-and-White Composite of Lower Lake Michigan from a Landsat I Image Taken on 10 June 1973 is Shown. Pollutant plumes are readily identified emanating from the shoreline.

ations of the surface water, indicated by some of the streak patterns near the western edge of the lake and by the fact that ship wakes near the center of the photo are easily recognized.

This particular example points out some of the difficulties of interpreting satellite imagery, viz. the variety of factors which can influence the discrimination of plumes against the underlying surface, in this case water. Some of the factors which affect overall image contrast include the spectral albedo of the lake surface through water turbidity or water depth (nearshore) variations, the amount of radiation backscattered by the plume, and diffusive light scattering by atmospheric molecules and haze layers, the latter being most important in heavily polluted regions.

The spectral dependence of light scattering by aerosols is also illustrated in Figure 1.28. Condensed water plumes, which are dominated by particles/droplets larger than 1-2 μm, are nearly neutral in their spectral scattering characteristics, while smoke plumes, which are dominated by particles smaller than 1 μm, scatter light preferentially in the blue. Thus, smoke plumes should show up in the 0.5-0.6 μm and 0.6-0.7 μm bands while condensed water plumes (like clouds) should appear equally well in all spectral bands.

Since each spectral channel is calibrated, it is possible, in principle, to determine aerosol optical depth (turbidity) from the upwelling radiance measurements. Analysis of this type has been applied to the study of dust storm aerosol[48] and to regional and global mapping of atmospheric turbidity.[49,50,51] Ground-truth turbidity measurements, made simultaneously during satellite overpass, provide an independent measure and probable error for this technique.[51] The method is most effective over low-albedo surfaces such as water. Turbidity values obtained from background or well-mixed urban haze by this method are reasonable, considering the number of assumptions about aerosol scattering phase functions, aerosol size distribution and aerosol composition that must be made because these quantities are fairly well defined and do not change rapidly with time. The situation for obtaining meaningful plume turbidity is questionable since, not only is the aerosol size distribution changing with time, but the condensed water plume also changes with time through dispersion and evaporation.

Use of satellite images for detection of particulate air pollution plumes and for estimating turbidity from areas of diffuse, well-mixed pollution appears promising. Additional images need to be examined to define the variability of surface albedo in order to extract the most information about plume dimensions and turbidities of widespread haze blobs. It would also be useful to speed up turnaround time for image reproduction -- at present it is on the order of one to two months. An idea, which is presently being explored by PNL, is to study the feasibility of additional ground receiving facilities.

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## PLUME RISE -- COMPARISON AND USE OF BRIGGS' FORMULAS

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Several widely used plume rise prediction equations are compared, and figures are presented to show the extent of the differences between them. One of the equations, which is applicable for buoyant plumes in a neutral atmosphere, is considered further. Graphs are presented to show the rise predicted under a range of meteorological and source conditions. These results can be used to estimate plume parameters in other applications.