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Darryl Randerson
Texas A&M University

A Study of Air Pollution Sources As Viewed by Earth Satellites

Several photographs are presented which illustrate the large scale dispersion of atmospheric pollutants. These photographs were taken by astronauts on various manned spacecraft flights. A spacecraft view of a forest fire in the Apalachicola National Forest revealed a rather large smoke plume. Geometrically scaled measurements indicated the plume was approximately 4 miles wide and about 65 miles long. Trapped under a frontal inversion located between 2500 and 3000 ft above ground level, this plume was being transported south-southwestward into the Gulf of Mexico by the local wind flow pattern. Several pictures containing examples of industrial smoke plumes in the vicinity of Houston, Tex., are discussed in relation to the local synoptic situation. A picture of industrial haze over Houston, Tex., is presented to illustrate an areal distribution of atmospheric pollutants covering an area of about 2600 square miles.

During the past five years photographs from the manned spacecraft have produced many impressive pictures of the earth. These color pictures have shown numerous interesting geographical and meteorological features. Fortunately, some pictures of air pollution occurrences are available, but their discovery required many hours of reviewing the photographs taken from all the manned spacecraft launched from Cape Kennedy. The pictures presented in this paper represent some of the best views of air pollution as seen from orbiting satellites.

Picture of Smoke Plumes in the Houston Area

Figure 1 was taken from Gemini–XI on Sept. 14, 1966 at about 0543 CST. The Southeast portion of the Texas Gulf Coast shows up rather well. Galveston Bay is distinguishable at the bottom center of the figure. Closer examination of the figure reveals that the southwest region of the Bay is obscured by effluent emissions from industrial smoke originating in Texas City. A reliable location of this pollution source is enhanced by identifying the Texas City Dike, a long narrow protrusion immediately to the right of the emission region.

Mr. Darryl Randerson is a Research Scientist in the Department of Meteorology, College of Geosciences, Texas A&M University, College Station, Tex. 77843.

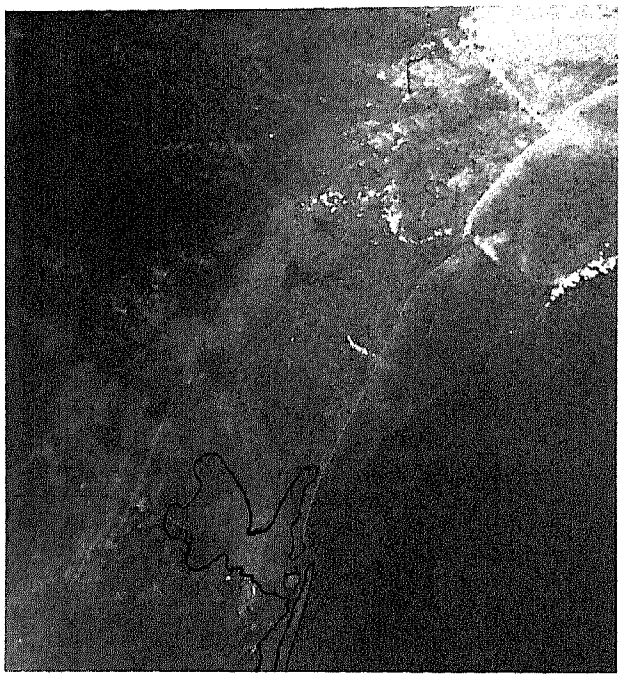
A short distance to the left of Texas City is the region of particular interest. Two or three parallel, narrow white streaks are easily seen to be oriented in an east-west direction. These streaks are close to the northwest shore of Galveston Bay. A more exact location was obtained by utilizing proportional measurements along with known, visible landmarks such as Atkinson Island (the island appearing white that is visible in the northwest extension of Galveston Bay). Geometric measurements indicated that the approximate source of the longest streak was about 10 miles west-northwest of the northern tip of Atkinson Island. The resulting position is on the south side of the Houston Ship Channel in the vicinity of several oil and chemical companies. Consequently, it was concluded that these streaks were smoke plumes extending from the chemical plants and oil refineries located east of Houston. Further measurements revealed that the principal smoke plume was at least 25 miles long. The plume could have been longer, however, the picture is not clear enough to suggest an extended length and the smoke plume probably became too diffuse to be resolved by the camera.

The thermal structure of the atmosphere at 0600 CST on Sept. 14, 1966 is given in Fig. 2: the atmospheric sounding for Victoria, Tex. Notice the presence of a shallow nocturnal temperature inversion just above the ground. The top of the inversion is about 450–500 ft above the ground. The atmospheric sounding for Lake Charles, La., was essentially the same and, for this reason, is not presented. Consequently, due to their apparent linear structure, the smoke plumes in Fig. 1 probably are trapped underneath a nocturnal inversion and extend eastward below this inversion as a result of the local circulation. Of particular interest is the fact that, just by looking at the visible structure of the longer smoke plume, two characteristic features stand out. First, the plume is clearly visible and persists for an extended length. Second, the plume appears to be compact. Both of these features imply atmospheric stability, lack of contact with the ground, and minimum turbulent mixing. Notice, in particular, that the width of the plume apparently remains constant along all of its visible length indicating that the horizontal component of turbulence is small.

Picture of Florida Forest Fires

Figure 3 was taken from Gemini-VII on Dec. 7, 1965 at about 1323 CST. The coastline visible in the figure is identified as the coastal region in the vicinity of Apalachicola, Fla. The sand covered islands located about five miles from the coast are easily recognized by their bright, white appearance. Panama City, Fla., also appears in the upper left-hand portion of the picture.

On Dec. 7, 1965 the Florida State Forest Service burned approximately 2200 acres in the Apalachicola National Forest. According to the Forest Service, the location of this controlled burn



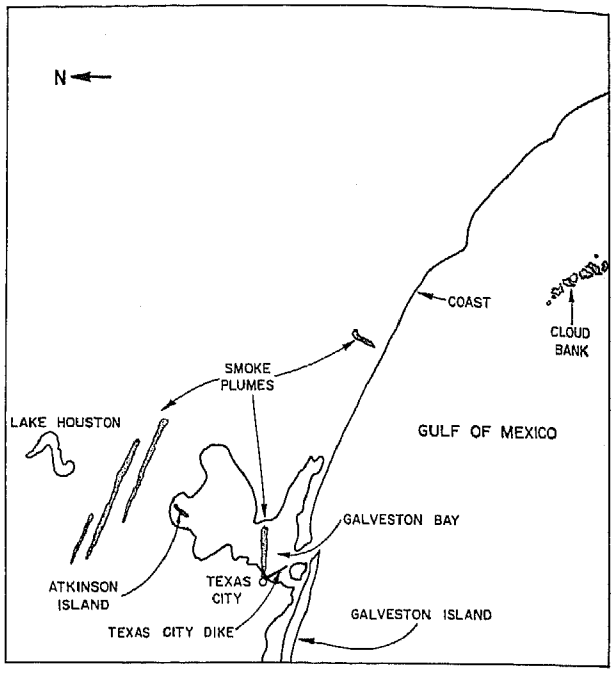


Fig. 1. A Gemini XI picture of industrial smoke emitted by oil and chemical companies located along the Houston, Tex. ship channel. This picture was taken on 14 Sept. 1966 at about 0543 CST. Galveston Bay is outlined at the bottom of the figure. Galveston Island is the long, narrow, outlined island protruding from the bottom center of the picture. The three individual smoke plumes oriented parallel to the coast are located near the lower left-hand corner of the figure and just to the left of Galveston Bay. Important landmarks are identified on the accompanying sketch.

was about 50 miles east of Panama City, Fla. and approximately 35 miles northeast of Apalachicola, Fla. Since the optical axis of the camera was essentially normal to the surface of the earth, the position of the forest fire was verified by utilizing the known landmarks visible in Fig. 3. Another smaller fire appears just south of Lake Talquin. To avoid duplication, the smoke plume associated with this fire will not be discussed.

During the period Dec. 7–9, the local atmospheric circulation over the southeastern United States was dominated by a large, continental polar anticyclone. Figure 4 represents the plot of the Dec. 7, 1965, 1200 CST low-level wind profile for Tallahassee, Fla., as well as the 1800 CST, Dec. 7, 1965 temperature lapse rate and wind profile for New Orleans, La. The resulting profiles and lapse rate are representative of the vertical distribution of the winds and temperature at the time the picture in Fig. 3 was taken. Notice that over Tallahassee the winds between the surface and 5000 ft are all northeasterly. A comparison of Fig. 3 with Fig. 4 shows that the smoke plume emitted by the forest fire has a northeast-southwest orientation parallel to the local circulation. Above about 6000 ft the air flow was more northerly. Another noteworthy feature is the thermal structure of the atmosphere over the pictured region. Only the New Orleans sounding is presented since the soundings for Montgomery, Ala., and Tampa, Fla., contained essentially the same thermal structure. Figure 4 shows a small inversion located about 300 ft above sea level. Since the picture of the forest fire was taken in the afternoon at about the time of maximum surface heating, this small, evening inversion probably did not exist. Even if this shallow stable layer had been present, the intense heat of the forest fire would have destroyed it. Of particular importance is the strong frontal inversion located between about 2000 and 3000 ft. Notice the northeasterly air flow below this inversion. By comparing Figs. 3 and 4 it appears that the pictured smoke plume is trapped below the frontal inversion in a northeasterly current of continental polar air.

Geometric measurements indicate that the smoke plume in the center of Fig. 3 is approximately 60–65 miles long and about 4 miles wide. This plume extends about 25 miles off the coast. From the limited data available, the coastal sea-water temperature below the smoke plume was probably

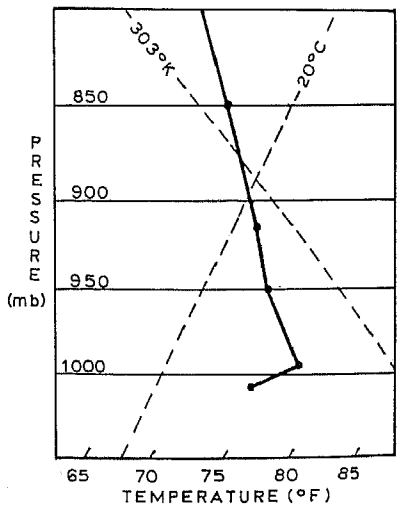


Fig. 2. A Skew T-Log P plot of the temperature lapse rate for Victoria, Texas at 0600 CST on 14 Sept. 1966.

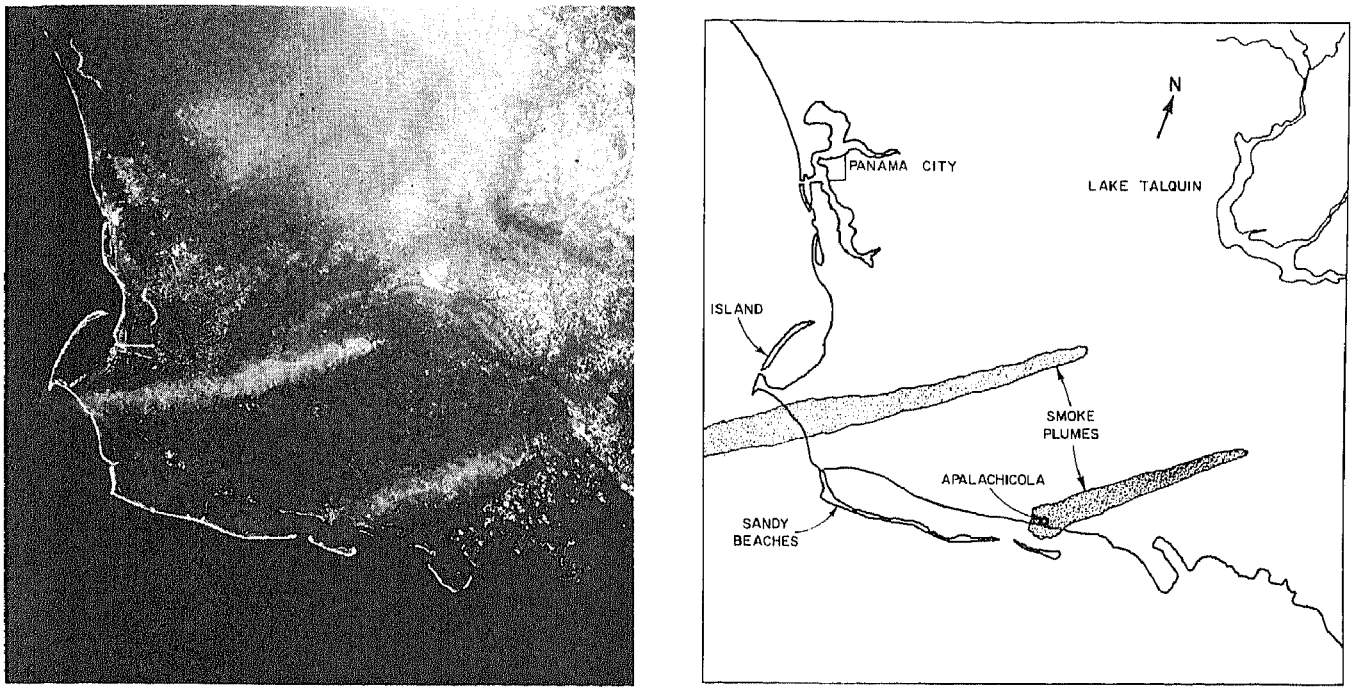


Fig. 3. A Gemini-VII picture of smoke plumes originating from forest fires in the Florida panhandle. The photograph was taken at about 1323 CST on 7 Dec. 1965. Important landmarks are identified on the accompanying sketch.

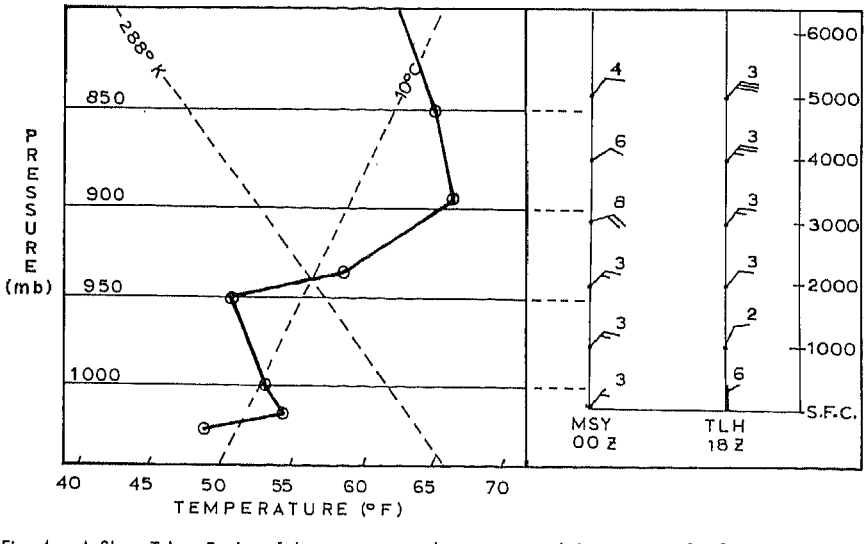


Fig. 4. A Skew T-Log P plot of the temperature lapse rate and the wind profile for New Orleans, La. (MSY) for 1800 CST on 7 Dec. 1965, and the wind profile for Talahassee, Fla. (TLH) for 1200 CST on 7 Dec. 1965.

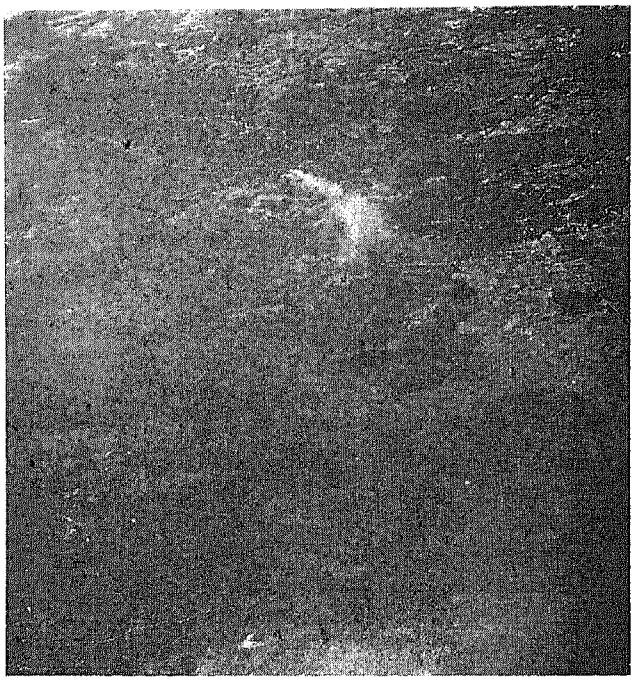


Fig. 5. A Gemini-VII picture of air pollution over East Texas. The picture time is about 1320 CST on 6 Dec. 1965. Important landmarks are identified on the accompanying sketch.

about 60°F; only a few degrees warmer than the maximum temperature for the day. Warmer water was found further off the coast. It is possible that this increased surface warming increased the atmospheric turbulence over the Gulf of Mexico, dispersing the visible smoke plume.

Picture of Air Pollution Over SE Texas

A different type of air pollution situation is represented in Fig. 5. This picture was taken from Gemini-VII on Dec. 6, 1965 at about 1320 CST. The picture is not overexposed, the white appearance is due to industrial smoke and haze over southeast Texas. Notice that the upper right-hand corner of the picture is sharper and not as "hazy" as the lower right-hand corner (northeast Houston). Just above the center of the picture is a smoke plume extending from a lumber mill in East Texas.

Surface synoptic weather reports indicated that at about the time the picture in Fig. 5 was taken a continental polar front had moved just to the south of Houston, Tex. Consequently, East Texas was under the influence of this cool air mass with a steady northeast flow of air existing from the surface to about 6000 ft. A representative description of the thermal structure of the atmosphere over East Texas is presented in Fig. 6; the 1800 CST sounding for Lake Charles, La. This figure shows that a rather unstable lapse rate existed from about 300 ft above sea level to near 2500 ft. This unstable layer was capped by a temperature inversion with a second unstable layer above. This secondary instability was located between about 3500 ft and 5500 ft where the base of a second inversion was found. Soundings from Shreveport, La., and San Antonio, Tex., indicated that the temperature inversion near the 3000-ft level might have been weak enough to permit vertical mixing through a greater depth over the Houston area.

Due to the oblique angle at which Fig. 5 was taken it was difficult to ascertain the length of the smoke plume in East Texas. However, it does appear obvious that the plume was fanning out more rapidly than the plumes pictured in Figs. 1 and 3. A comparison of the data presented in Fig. 6 with that in Fig. 4 reveals several noteworthy facts. First, the smoke plume in Fig. 3 apparently is located beneath a strong temperature inversion with winds less than about 15 knots and essentially no vertical wind shear above the surface layer. The primary smoke plumes pictured in Figs. 3 and 5 occurred 24 hr apart, in the afternoon, in the same polar air mass. Second, vertical mixing of the smoke plume in Fig. 3 would be less than that in Fig. 5 since the temperature inversion over the Florida panhandle (Fig. 4) was much stronger than the one over East Texas (Fig. 6). Apparently the air flow over the Florida panhandle was more uniform both vertically and horizontally than the circulation over East Texas. Figure 5 gives the impression that the horizontal component of turbulent mixing was much greater than that in Fig. 3. There is also the possibility that more horizontal wind shear existed in the East Texas case than in the Florida case, causing more horizontal dispersion.

An attempt was made to ascertain the extent of the areal coverage of the smoke-haze pollution pictured in Fig. 5. The technique utilized was elementary and involved personal judgment. Obviously the lower right-hand corner of Fig. 5 is covered with a thick layer of polluted air. Reference to Fig. 7 illustrates the reduction in visibility around the Houston International Air-

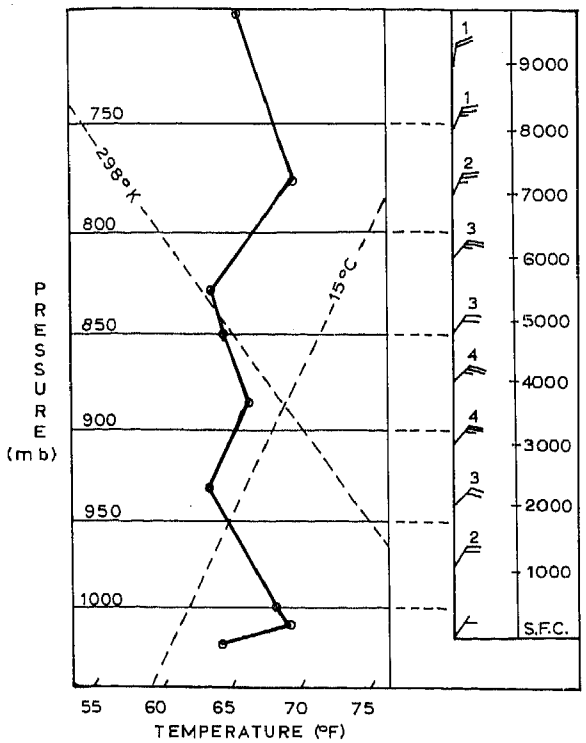


Fig. 6. A Skew T-Log P plot of the temperature lapse rate and the wind profile for La Charles, La. for 1800 CST on 6 Dec. 1965.

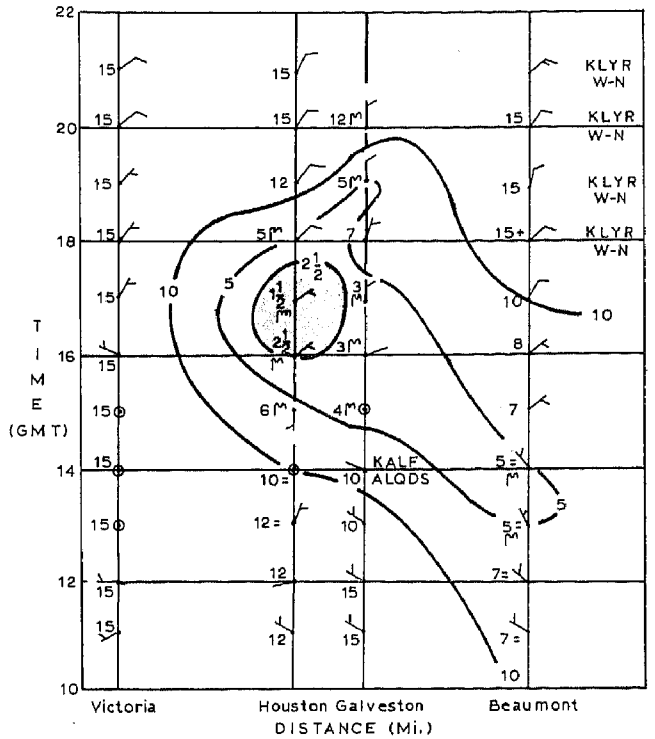


Fig. 7. Visibility in miles in a time-space coordinate system for 6 Dec. 1965 between Victoria, Tex. and Beaumont, Tex. Notice the low visibility at Houston, Tex. between 1000 CST and 1200 CST. The letters K LYR W–N mean smoke layer West through North; K ALF ALQDS means smoke aloft all quadrants.

port just before the picture in Fig. 5 was taken. If only the right-hand quarter of Fig. 5 is assumed to be obscured in smoke and haze the areal, horizontal coverage is about 2600 square miles. This coverage is clearly an underestimate since some of the "haze" apparently extends to the left side of the figure and since only a portion of the polluted region has been pictured in the photograph. Regardless of the limited coverage of the picture, the significant result is the fact that an estimate was obtained of the actual coverage of a specific geographic region by a polluted mass of air. By having available and by utilizing such photographs to determine the areal distribution of air pollution in three-dimensions, a better understanding will result of the physical processes involved in the mesoscale and, eventually, the macroscale transport of polluted air.

Summary

The use of satellite photography of the earth can be very beneficial to the scientific study of the dispersion of pollutants in the atmosphere. Figures 1, 3, and 5 clearly show the distance over which pollutants can be transported as well as the effects of various atmospheric conditions upon the dispersion of pollutants. The large scale pollution pictured in Fig. 5 is particularly important because of the vast area it covers. Where did all this pollution come from? Is the primary source the emissions from industry and automobiles in the city? How much of this pictured haze cover originated at the lumber mill in East Texas? What is the vertical depth and concentration? Is the maximum concentration aloft or at the ground? The answers to such questions would be purely speculative without access to more data and more pictures similar to Fig. 5. Such photographs would be extremely valuable if at least one high quality picture was taken of the same geographical area on each complete orbit. This would be especially so if previous arrangements had been made to take extensive surface and upper air meteorological and aerometric measurements over a selected region. Such a program would produce valuable information on the areal dispersion of pollutants in three-dimensions and permit studies of such challenging problems as regional and global transport.

High resolution satellite pictures would be very helpful in obtaining reliable values for the downwind and crosswind dimensions of smoke plumes. Such direct measurements would produce data applicable to mathematical models of the diffusion of atmospheric pollutants.

It has been shown that satellite photographs of air pollution are helpful in determining a pollutant source region. Such pictures could be used to determine whether or not the pollution is interstate or intrastate. This information might be useful for enforcing future clean air legislation.

Acknowledgments

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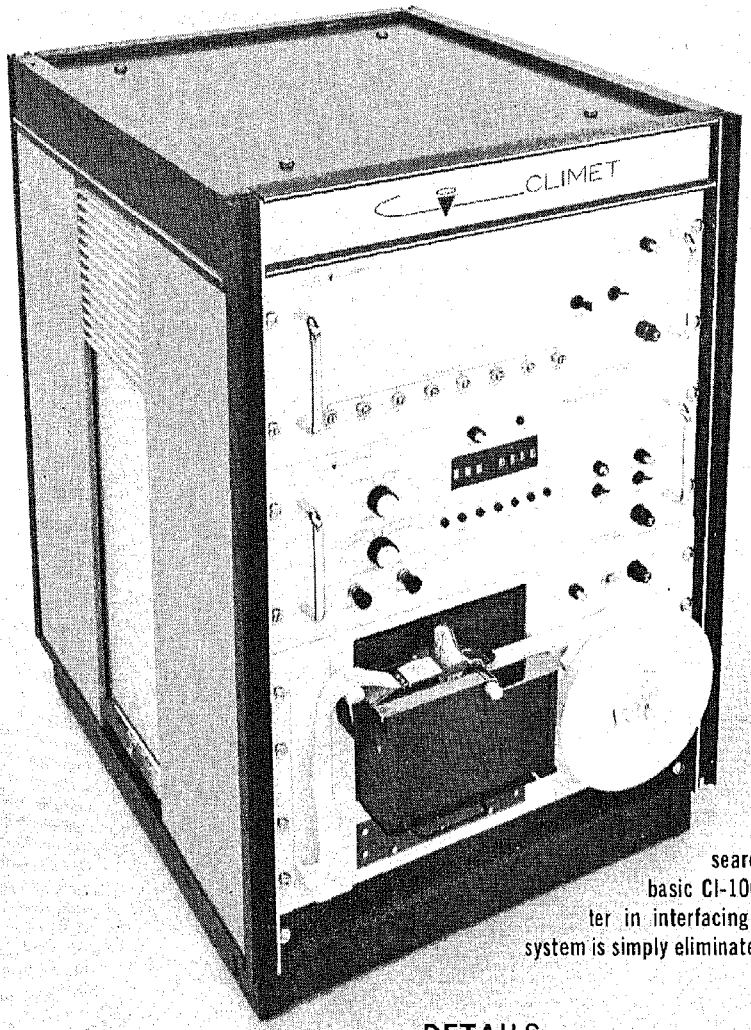

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