during the refraction of the radio waves back to earth. Backscatter from land should show only the ionospheric spectrum shifts. A few observations at other times indicate that the split spectrum is not uniquely associated with the sea during a hurricane.

The split Doppler spectrum is not always shown as clearly. Sometimes one component is emphasized, and sometimes a third component corresponding to a condition of no surface-generated Doppler shift is also present. This component may possibly originate from nearby land contributions or from certain sea-state conditions.

During times of ionospheric disturbance, a sea-scatter spectrum record may appear as in Fig. 2. The spectrum is again sometimes recognizably split despite the large superimposed ionospheric Doppler perturbations. Backscatter samples from regions where the sea-wave motion was predominantly in one direction would be extremely difficult to identify as sea scatter under such disturbed conditions.

These observations suggest that, under favorable ionospheric conditions, the spectrum signatures of ionospherically propagated backscatter from the surface of the earth could be used to determine whether scatter was from land or sea. In addition, stronger emphasis of one component over another might be used to deduce sea-wave direction, other sea-surface conditions, and thus wind or weather systems over the several hundred thousand square kilometers of sea surface observable by a properly placed backscatter sounder at distances of several thousand kilometers.

Further research into these aspects of backscatter sounding is required before feasibility or usefulness of high-frequency ionospherically propagated backscatter for the monitoring of sea or, indirectly, of meteorological conditions can be established.

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12 July 1967

Modeling Air Pollution in the Washington, D.C., to Boston Megalopolis

Abstract. *Simplified meteorological models and pollutant source configurations were used to demonstrate the types of pollutant patterns that might be encountered in the Washington, D.C.–Boston megalopolitan corridor. A semirealistic source distribution and source intensity of carbon dioxide were used in this demonstration. The results of the computations suggest that local increases in quantities of pollutants may at times require regional rather than local source consideration.*

At the present time, the study of air-pollution patterns over areas as large or larger than a state has received but little attention. Air-pollution studies are now generally directed toward understanding the source distribution and meteorological characteristics of specific metropolitan or local areas. As population and industrial activity increase, it seems reasonable to expect that an airborne pollutant from one metropolis may occasionally contribute to the total loading of that pollutant in another and that both might have a dominant effect on the air quality in the intervening rural areas. Such conjecture might be expected to be most valid in the heavily settled and highly industrialized section of the eastern seaboard between Washington, D.C., and Boston. I investigated pollution patterns in two specific situations: (i) patterns in which the wind blows continuously along the Washington, D.C.–Boston axis and (ii) annual average pollutant patterns associated with an annual wind-direction distribution.

The pollutant used for demonstration purposes is carbon dioxide as estimated from total values of fuel usage in each state. Information on state fuel usage was obtained in discussions with personnel of the American Petroleum Institute (Washington, D.C.), the Bureau of Mines, Department of Interior (Washington, D.C.), the Institute of Gas Technology (Chicago, Illinois), and the National Coal Association (Washington, D.C.). In all cases, the calculated CO_2 values are increments to be added to the natural background. The total amounts of fuels used in each

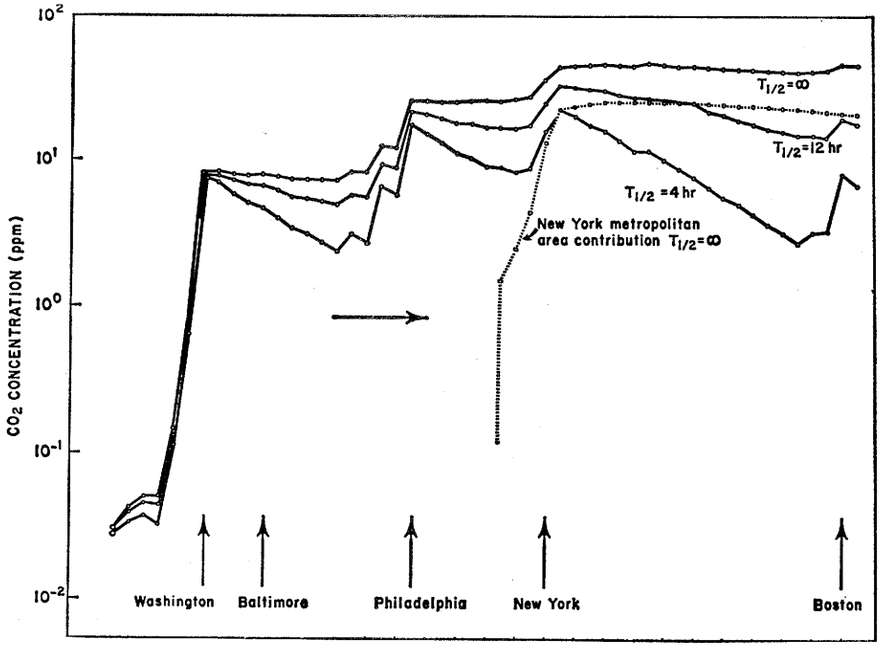

Fig. 1. Distribution of concentration increment above background along the Washington, D.C.–Boston axis for winds blowing continuously from Washington, D.C., toward Boston. Divisions on the abscissa are 30 km apart. Neutral stability conditions, an 800-m mixing depth, and a wind speed of 5 m/sec are assumed. The profile for infinite half-life ($T_{\frac{1}{2}} = \infty$) represents CO_2 concentration while the profiles ($T_{\frac{1}{2}} = 12$ hours and $T_{\frac{1}{2}} = 4$ hours) might represent the concentration of a gas released at the same rate as CO_2 but possessed of the appropriate half-life. The New York City metropolitan area contribution to the total concentration is also indicated.

state were divided among the counties in that state in proportion to county population. It was assumed that burning of the fuels within these counties resulted in about three mass units of CO_2 per mass unit of fuel consumed (with the ratio varying slightly for different fuels). Carbon dioxide was used as the tracer gas primarily because emission values are rather insensitive to variation in fuel type or combustion method. This tracer may be considered to be some gas, X, produced in proportion to total fuel usage and population distribution.

The CO_2 source values were used in two different models. In the first model, the equation for the concentration at various downwind distances from the source county was obtained from the commonly used Gaussian distribution function (*1*) and is given by

$$\bar{\chi} = \frac{Q}{(2\pi)^{\frac{1}{2}} (\sigma_{y_0}^2 + \sigma_y^2)^{\frac{1}{2}} D\, \bar{u}} \times \left\{ \exp - \left[\frac{y^2}{2(\sigma_{y_0}^2 + \sigma_y^2)} + \frac{0.693\ (t)}{T_{\frac{1}{2}}} \right] \right\} \quad (1)$$

where $\bar{\chi}$ is the average concentration (g m^{-3}) later converted to parts per million (ppm); Q is the source strength (g sec^{-1}); σ_{y0} is one-fourth of the diameter of a circle of area equal to a particular county's area (m); σ_y is the standard deviation of cross-plume concentration, a function of distance, and is obtained by a power function fit to the diffusion parameters presented by Gifford (*2*) and extrapolated as far as necessary (m); D is depth of atmosphere through which the plume is mixed (m) [see Holzworth (*3*)]; $\bar{u}$ is average wind speed (m sec^{-1}); y is lateral distance from plume center line to computation point (m); t is travel time from a county center to a computation point (sec); and $T_{\frac{1}{2}}$ is a half-life (in seconds).

The decay exponential was included so that the model might be interpreted in terms of some other pollutant which might be released in proportion to CO_2 but which would be affected by various scavenging mechanisms during its travel.

The downwind concentration in the pollutant plume described by Eq. 1 was computed for each of 110 counties situated within approximately ± 150 km of the Washington, D.C.–Boston axis. The contribution of each county's plume to each of 50 possible grid points (15 km apart) on the center line was obtained, and all contributions were summed at each grid point.

A variety of different meteorological parameters and half-lives were programmed to obtain values for a broad range of possible situations (Fig 1).

When we consider the three curves as representing three different hypothetical pollutants released in identical quantity, it can be seen that, for the same maximum permissible concentration (10 ppm, for example), the pollution in this situation would be a problem in the entire region from Philadelphia to Boston for the infinite or 12-hour half-life material, but would constitute an essentially metropolitan problem for the 4-hour half-life material. The effect of the New York City metropolitan area on maintaining high pollutant concentrations between New York and Boston is also shown in Fig. 1. The New York metropolitan area was defined as comprising 15 counties extending about 150 km along the computation axis and 40 km to either side.

The model was also evaluated for a flow from Boston to Washington, D.C. These results showed as ever-increasing burden of pollutant toward Washington, D.C., in the case of the infinite half-life material, with highest values between New York and Wilmington.

In that this first model represents only one of many possible situations, another model was designed to depict the average annual pollutant concentration in two dimensions rather than in one. For this model, an additional 35 counties were added to the original 110. The model consisted of the diffusion equation for the long-period aver-

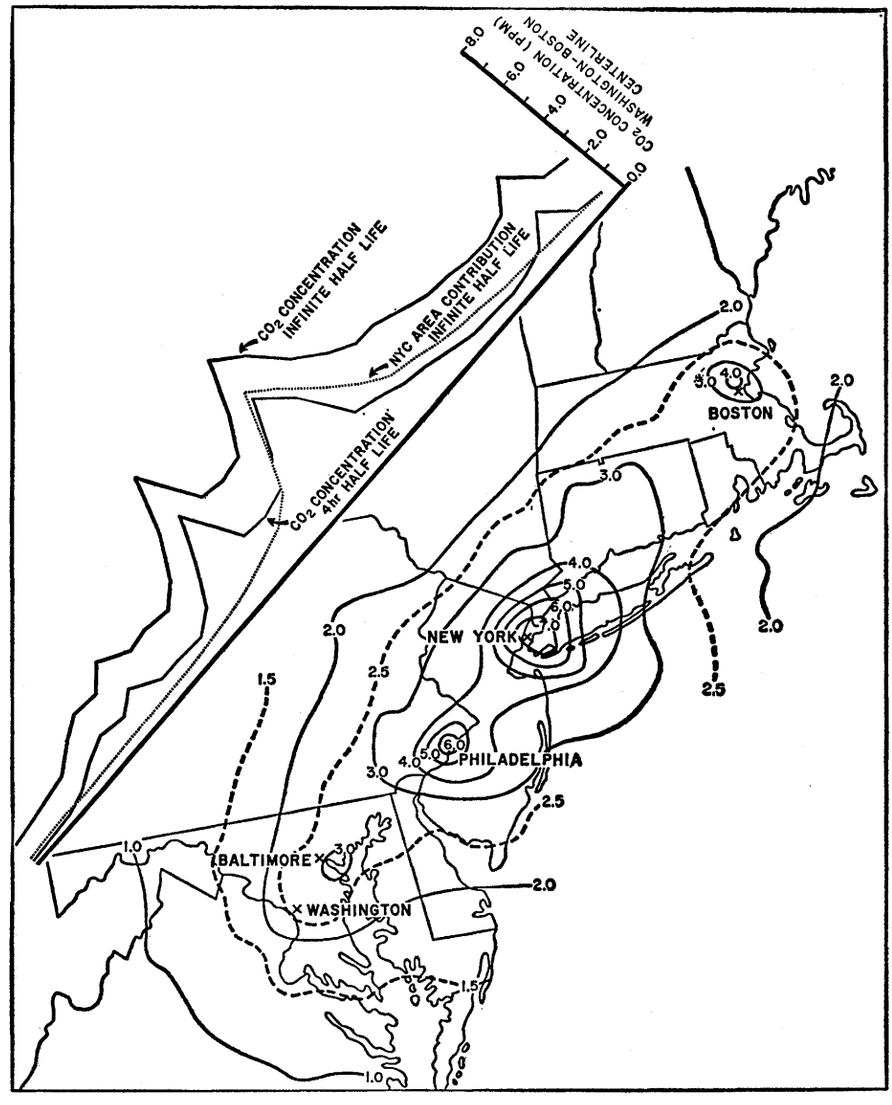

Fig. 2. Isopleths of increment of average annual concentration (ppm) above background for CO_2 ($T_{\frac{1}{2}} = \infty$) and various graphs of concentration plotted against distance along the Washingotn, D.C.–Boston axis. Neutral stability, a wind speed of 5 m/sec, and an 800-m mixing depth were assumed.

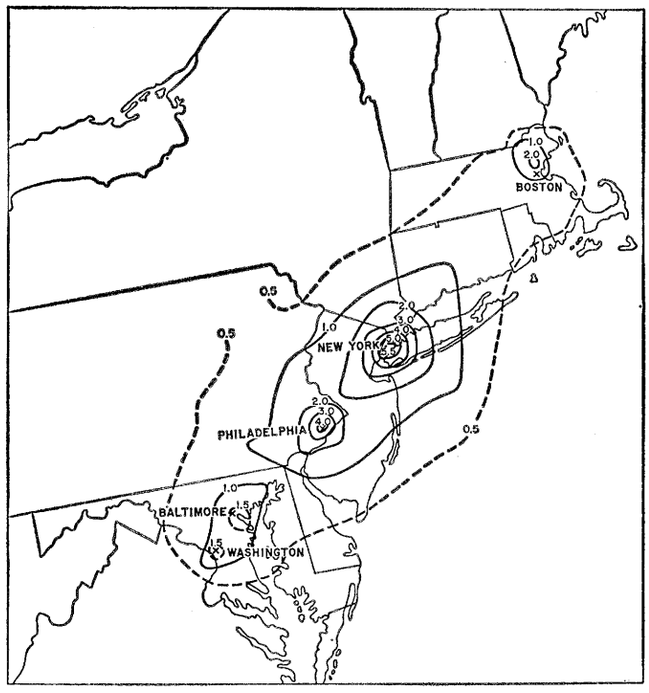

Fig. 3 (left). Similar to Fig. 2, but for $T_{\frac{1}{2}} = 4$ hours.

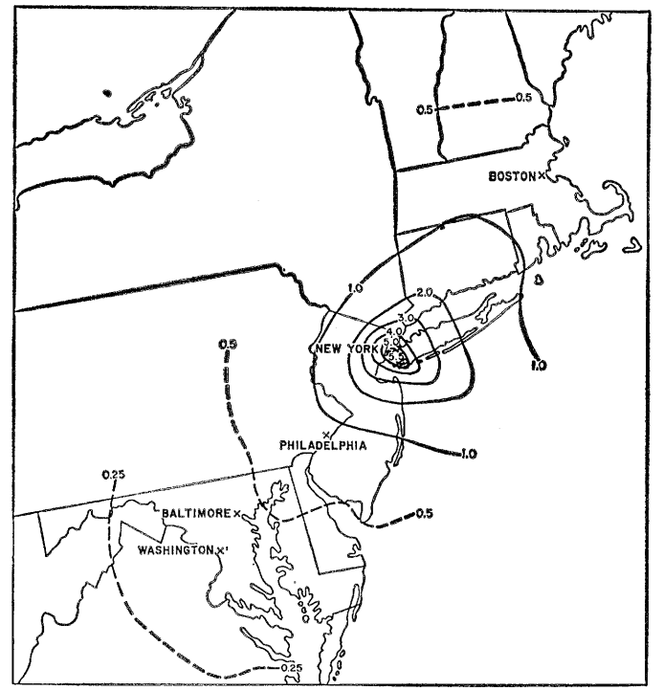

Fig. 4 (right). Contrbution of CO_2 from 15 counties in the New York City area only ($T_{\frac{1}{2}} = \infty$).

age (*4*) integrated vertically and divided by the mixing depth. It thus becomes essentially a "box" model given by

$$\bar{\chi} = \frac{PQ}{D\left(\frac{2\pi r}{16} + y\right)\bar{u}} \cdot \exp\left(-\frac{0.693t}{T_{\frac{1}{2}}}\right) \quad (2)$$

where P is the fractional frequency of the wind direction into 16 direction sectors, each 22 ½° wide and centered on north, north-northeast, northeast, and so forth; r is a distance from a source to a grid point (m); y is the diameter of a circle of area equal to that of a particular county (m); and the other terms are as given earlier. One set of annual wind-direction frequencies, an average of the Boston, New York, Philadelphia, and Washington, D. C., frequencies, was used for P. A wind speed of 5 m sec^{-1} was used for all directions. The contribution of each of the 145 counties to each of 429 grid points was then determined, and the total of all of the contributions at each grid point was obtained. The computer printed the total concentration values in the form of a grid that could be superimposed on an appropriate map and drawn directly as isopleths.

The map of CO_2 concentration is shown in Fig. 2, along with various graphs of concentration plotted against distance along the Washington, D.C.–Boston axis. Maximum values lie along this line because of the almost exact orientation of the major population centers on the line and also because of the comparatively high frequency of winds from Washington, D.C., to Boston.

The effect of assuming zero transport in through the boundaries of the model probably results in lower concentrations near these boundaries. The ocean was not considered as a source or sink of CO_2 in this computation.

Figure 3 displays the result of a similar computation for a 4-hour half-life material released in the same quantity and configuration as CO_2. Figure 4 shows the concentration distribution from the 15 counties in the New York City metropolitan area with the assumption of an infinite half-life. Comparison of Figs. 2 and 4 shows that the New York area contributes 30 percent of the average concentration increment above background over the entire megalopolis and about 15 percent of the incremental values over Washington, D.C., Philadelphia, and Boston.

Figures 2, 3, and 4 together illustrate one of the difficulties in attempts at local air-pollution control and legislation within a megalopolitan area. Depending on the nature of the pollutant and the levels of relatively safe concentration, an air shed for a locality may not extend beyond that locality's boundaries or may extend throughout the megalopolis and beyond (compare Fig. 2 with Fig. 3, assuming a maximum permissible concentration of 2.0 ppm). Further, some localities (for example, Princeton, New Jersey) might find that enactment of legislation concerning clean air on a strictly local basis would produce less than the desired result when, on the average, much of their problem comes from widely separated major sources.

Besides the possibility of hazard to the population, farming and possibly the entire ecological balance of rural regions in the megalopolis may be affected by the interplay of pollutant emissions and meteorological variations. Again, the geophysical environment in a megalopolis may undergo more subtle modification; for example, Schaefer (*5*) reported on ice nuclei from the exhausts of automobiles.

The computed CO_2 values are used here as indicators of general pollution patterns. However, comparison of the magnitude of these estimates with measurements of CO_2 fluctuations due to noncombustion (natural) sources is of interest.

The CO_2 concentrations shown in Fig. 2 appear to be rather low. However, Clarke and Faoro (*6*) estimate average background CO_2 increases in a 100-m layer due to natural CO_2

sources during the night in the growing season as 25 to 70 ppm (the latter an extreme) above background. Multiplying the values (Fig. 2) by 8 to account for the difference in mixing depth and then by a factor of 2 or 3 to account for the fact that the Clarke-Faoro values occur only during the growing-season night (while the data in Fig. 2 are annual averages) gives annual background increases due to combustion processes generally larger than these natural source values, at least in the Washington–Boston corridor. The conditions of the two models presented here tend to average out the peak concentrations observed within a particular city.

As in all studies of pollution from a multitude of sources, the two important modeling criteria are the meteorology and intensity, distribution, and characteristics of the source material. The meteorological models used here are of the type intended for use over distances of up to a few tens of kilometers. As such, they ignore systematic variations of wind direction between the source and the computation point, perhaps an important consideration in this megalopolis bounded by a mountain range and an ocean. A number of other simplifications, such as ignoring diurnal changes and correlations between wind direction and mixing depth, probably have some effect on the derived patterns. However, on the regional scale considered here, our knowledge of the meteorology of the situation may be greater than our knowledge of the sources. The variety of the possible pollutants of interest, the location of their production, their varying rates of emission, the physical, chemical, and photochemical reactions between various pollutants and classes of pollutants, and the difficulty of correctly measuring their concentrations are but some of the complications. On the regional scale considered here, source inventory data from both metropolitan and nonmetropolitan locations are needed.

The calculations discussed in this note were performed by a CDC 6600 computer. A complete run for each of the models took about ½ minute and included individual output for two or three different values of wind speed, mixing depth, and half-life.

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14 July 1967

Concurrent Isolation from Patient of Two Arboviruses, Chikungunya and Dengue Type 2

Abstract. *Chikungunya virus and dengue type 2 virus were isolated from a single blood specimen taken from a patient in the acute phase of a dengue-like illness seen at Christian Medical College Hospital, Vellore, South India, in October 1964. In serial blood specimens collected from this patient there was an increase in antibody to these same two viruses. The technique for unmasking an agent (such as dengue) with a long incubation period in mice in the presence of an agent with a short incubation period is described.*

Occurrence in humans of dengue-like illnesses caused by chikungunya virus, a Group A arbovirus, and by dengue viruses of Group B has been reported from several regions in the Orient, including India (*1*). The patients' responses have ranged from fever with general malaise to a syndrome marked by hemorrhagic phenomena, shock, and death. The term "hemorrhagic fever" has been applied to several outbreaks. Demonstration of viremia or antibody response, or both, in members of the population at risk has shown that during the outbreaks viruses of groups A and B may be active at the same time and in the same place. Serologic evidence of simultaneous infection by viruses of these groups, presumed to be chikungunya and dengue, has been obtained in a number of instances. To our knowledge, however, no instance of proved dual viremia resulting from naturally acquired arbovirus infections has been reported.

In the latter half of 1964 an epidemic of dengue-like illness, associated in some cases with mild hemorrhagic phenomena, occurred in Vellore, South India. We attempted to isolate virus during this time, and took blood samples from 372 patients of the Student-Staff Health Clinic, Christian Medical College Hospital; chikungunya virus was recovered from 195 of these patients, dengue type 1 virus from one, and dengue type 2 virus from three (*2*). Serologic tests on paired or serial blood specimens from 332 of the patients showed that seven patients responded to infection with a simultaneous increase in antibody to both chikungunya and dengue virus antigens. Two of these patients, from whom blood specimens had been taken on consecutive days, were roommates. Both were febrile when first examined in the clinic, and both reported pain in the joints, a common symptom in cases of chikungunya treated in Vellore (*3*); no unusual features suggestive of dual infection were reported or observed during the illnesses of these individuals. Initial specimen 10939-1 from one of these two patients yielded a strain of dengue type 2 virus; initial specimen 10935-1 from the other yielded a strain of chikungunya virus. In October 1965, we attempted isolation of dengue virus from specimen 10935-1, which had been stored in a Revco freezer at −50°C.

Three different mixtures were prepared in sterile test tubes. The first contained equal amounts (0.15 ml) of serum specimen 10935-1 and mouse antiserum to chikungunya virus; the second, similarly, specimen 10935-1 and phosphate saline containing 0.75 percent bovine albumin (BAPS); the third, similarly, specimen 10935-1 and normal mouse serum. Before they were injected into mice, the mixtures were placed in a 37°C bath for 1 hour. Two litters of infant mice (less than 24 hours old) were inoculated per tube, each mouse receiving 0.02 ml intracerebrally; the mice were then observed daily for signs of illness.

The four litters of inoculated control mice, that is, those injected with a mixture of specimen 10935-1 and either BAPS or normal mouse serum, presented a picture typical of the rapid, overwhelming effect of chikungunya virus infection. All the mice showed signs of illness within 2 to 3 days; some died as early as day 3; none recovered. The brains were shown by complement-fixation test to contain chikungunya virus. One of these strains was designated 10935-1C.

The two mouse litters inoculated with a mixture of specimen 10935-1 and mouse antiserum to chikungunya virus presented an entirely different picture. In only four of the 12 mice