A Pilot Experiment Using Indium as Tracer in a Convective Storm[1]

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ABSTRACT

In an effort to determine whether it is feasible to use tracer techniques in the study of circulations and rain scavenging processes in severe convective storms, a pilot experiment using indium as tracer was conducted. A total of 200 gm of indium was released over a period of 21 min into the updraft feeding a relatively small convective system. The tracer was released by means of pyrotechnic flares from an airplane flying at about 3200 ft altitude. The rainfall from the system was sampled at the ground by means of an array of samplers placed and recovered by two mobile units. Analysis of the samples compared against analyses of untagged rain samples and reagent backgrounds of indium distinctly indicates the presence of tracer indium in a reasonable distribution pattern.

1. Introduction

The experiment described here is a remarkably simple one, but one for which the chances of success seemed rather small. As an outgrowth of several years' studies of the removal of contaminants from the air by rain (Gatz and Dingle, 1963; Dingle and Gatz, 1966; Gatz, 1967), we came to the decision to try to place our own tracer into a convective rain-generating system to see whether we could recover it in measurable quantities in rain samples collected at the ground downstream.

Experiments such as this are necessary for some and significant for all of the following areas of current interest: 1) the natural cleansing of the air by rain, 2) the details and the effects of the circulations within convective storms, and 3) the possible beneficial application of modification techniques to violent convective storms. A more complete discussion of each of these areas is in preparation (Dingle, 1969), although basic information on the first two can be found in Junge (1963), Browning (1964), Dingle (1965), and Newton (1966), for example.

2. Objective

The objective of this initial experiment was solely to determine whether such a tracer experiment is feasible. In placing tracer material into the updraft of a strong convective storm, one may have considerable doubt. The principal criterion for success at this stage is therefore that the tracer be clearly identified and measured in rain samples collected so as to bear a reasonable relationship to the initial placement of tracer.

This overall criterion obviously encompasses others, such as the feasibility of striking a "target" area with tracer-tagged rain, and that of coordinating adequately the tracer-releasing aircraft with the ground-level rain sampling system. It suggests but does not include the more comprehensive objective of sampling so as to determine the ground-level deposition pattern of the tracer, and thence estimating the overall rates of diffusion achieved by the diverse processes of circulation, condensation, scavenging and precipitation.

3. Selection of tracer and emission system

The factors which control the selection of a suitable tracer material include those properties that determine how it may be dispensed and how scavenged, and the technique that will be used to identify and measure it. Of these, the last is the *sine qua non*, so it was chosen first.

On the basis of sensitivity and demonstrated reliability, in addition to the accessibility of the necessary neutron source and facilities at the Phoenix Memorial Laboratory, The University of Michigan, we decided to use neutron activation analysis. Consideration of the nuclides and isotopes that might be used (Goldman and Stehn, 1962) led to the selection of indium as the element best suited to measurement by neutron activation. In this search we were aided materially by earlier work done by Duce *et al.* (1963), Gordon and Larson (1964), and Jones *et al.*, 1967).

Stable In-115 is converted to In-116*m* by neutron capture. The latter is radioactive, emitting both beta and gamma rays with a half-life of 54 min. The neutron capture cross section is 150 barns, so the activation is relatively efficient. Details of the analytical procedure are presented in a companion paper (Gatz *et al.*, 1969). Suffice it here to say that the sensitivity limit for the detection of indium in our laboratory is 10^{-10} gm within $\pm 5\%$.

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Selection of the method for dispensing the tracer was influenced strongly by developments that had already taken place in silver iodide cloud seeding technology (Fuquay, 1960; St. Amand and Donnan, 1963; Finnegan *et al.*, 1967). Our needs appeared to be very similar to those of the cloud seeders: small particle-size, airborne emission with precise placement, and good control of the quantity of material emitted. For several reasons involving both procurement and operations, we chose to use pyrotechnic flares containing In-115 in the form $InCl_3$ as the source of our tracer. These burn at an estimated temperature of about 1200C, vaporizing the indium trichloride, and probably producing chemical complexes of In with Cl, O and some of the metallic constituents of the pyrotechnic compound (e.g., K and Mg). This chemical behavior is currently under study. The flares are carried at the trailing edge of the aircraft wing by means of supports designed for the purpose, and each flare is activated by electrical ignition from the cockpit.

4. Experimental procedure

The site and the season for the experiment were dictated by our collaboration with the National Severe Storms Laboratory during late spring. By this arrangement, mesonetwork data, special soundings, and comprehensive radar data of high quality are available to establish the meteorological setting of our various field experiments in substantial detail.

In particular, this pilot experiment was conducted on 30 May 1967 on a relatively small convective storm within a pre-cold-frontal squall line near the town of Holdenville, Okla. The location is shown in Fig. 1, the synoptic situation in Fig. 2, and pertinent radar PPI echo contours in relation to the sampling array in Fig. 3.

Emission of indium tracer was initiated at 1511 CDT at an altitude of 3200 ft MSL in an updraft estimated at 1400 ft min^{-1}. The initial point of release was 6 mi west of Holdenville, and 2 mi east of the rain curtain. (Fig. 4). The airplane traversed the updraft on a track roughly perpendicular to the storm movement, made a 180° turn and retraversed the updraft and repeated this procedure, staying at a nearly constant distance ahead of the rain curtain. The emission continued for 21 min during which a total of 200 gm In was released. The updraft decreased in width and intensity during this time from ~5.0 mi, 1400 ft min^{-1} to ~3.0 mi, 500 ft min^{-1}.

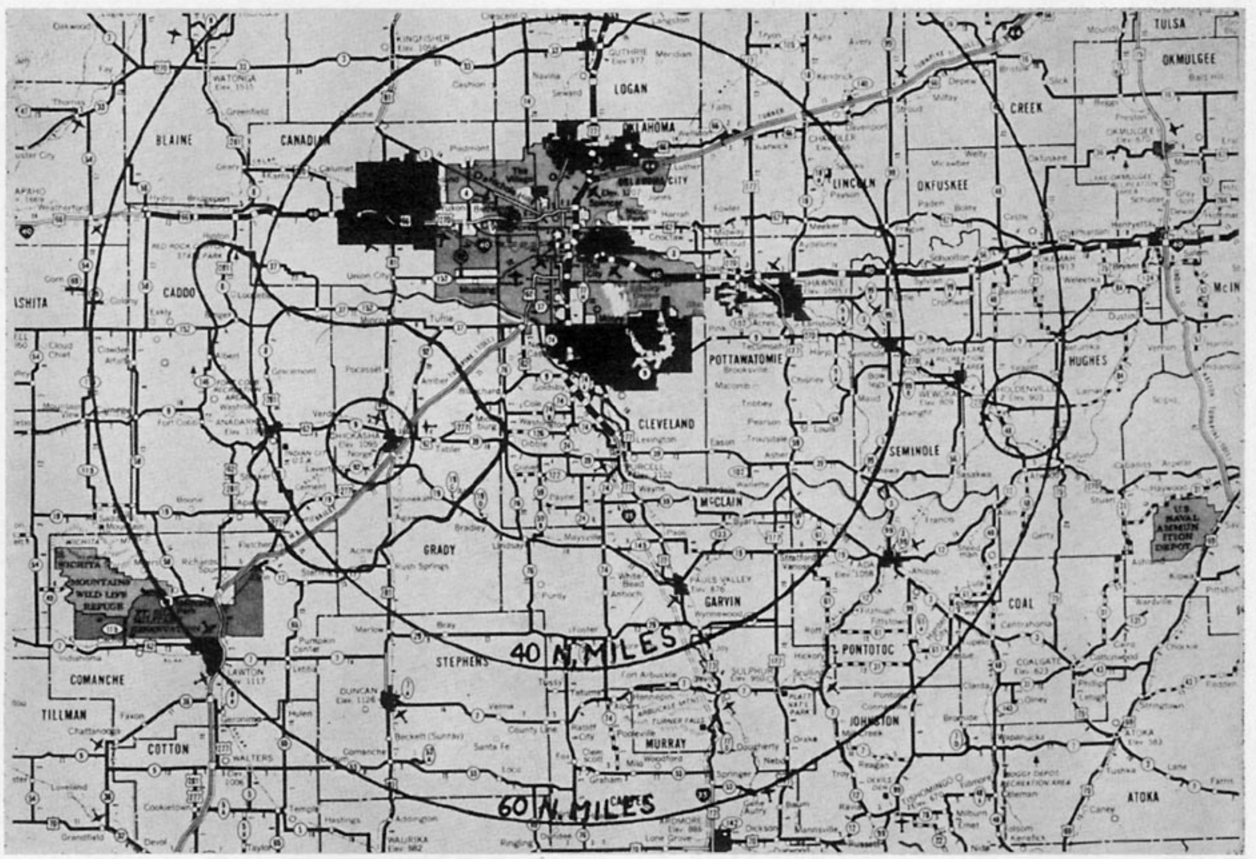

Fig. 1. Map showing location of the pilot tracer experiment near Holdenville, Okla., in relation to the National Severe Storms Laboratory at Norman (40 and 60 n mi range circles centered on NSSL radar), the University of Michigan field station at Chickasha, and the Agricultural Research Service Washita River Watershed study area (irregular figure which includes Chickasha). The entire area shown is within the mesonet of stations operated by NSSL.

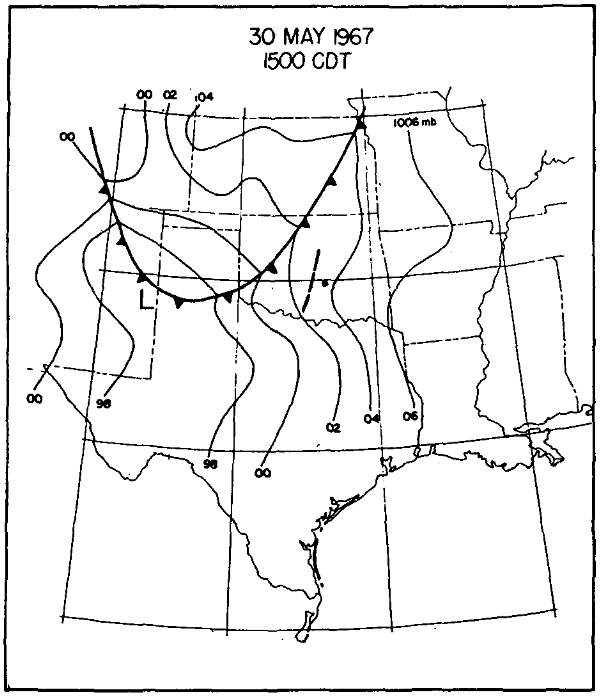

FIG. 2. Local synoptic weather map showing cold front position as of 1500 CDT 30 May 1967. Dashed line shows approximate position of squall line deduced from NSSL radar data; dot is approximate location of Holdenville.

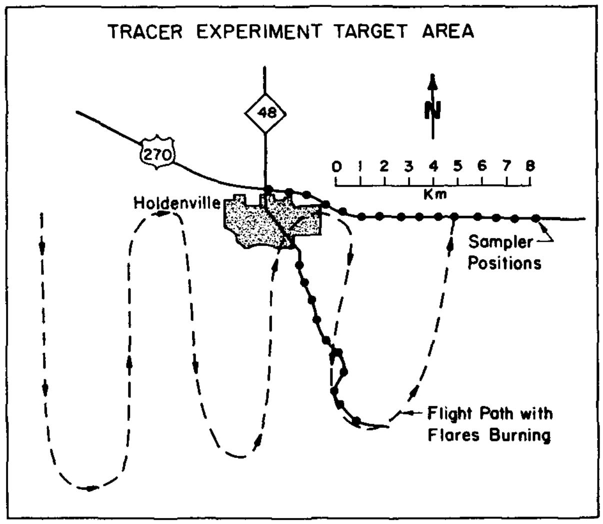

FIG. 4. Path traveled by the airplane during emission of indium tracer. Start of emission at 1511, end at 1532 CDT. Position of airplane was maintained in the major leading updraft about 2 mi east of the leading edge of the rain. Updraft speed decreased from about 1400 *to* 500 *ft min*$^{-1}$ *and width changed from* $\sim$5 *to* $\sim$3 mi during the tracer emission period. Ground level samplers (Fig. 5) were placed as shown by the dots along U. S. highway 270 and state route 48.

Rain samples were collected at ground level at the points indicated in Fig. 4 along state route 48 and U. S. highway 270. Samplers were distributed using two carry-all trucks, each manned by a driver and an assistant and supplied with 20 roadside samplers (Fig. 5) previously prepared for rain collection. In setting the samplers, each was pre-inoculated with 50 ml of 6N HCl and then attached to a roadside fence for support against wind gusts.

As indicated by the map (Fig. 1), the mobile units had to operate a long way from their home base in this case. The temporal coordination of the operations was therefore less than ideal, and most of the samplers were placed after the rain had begun at their respective stations. Samplers were placed along each road between 1528 and 1553 CDT, the sequences being from west to east and from north to south, respectively. They were retrieved immediately following the rainshower, finishing by 1645 CDT.

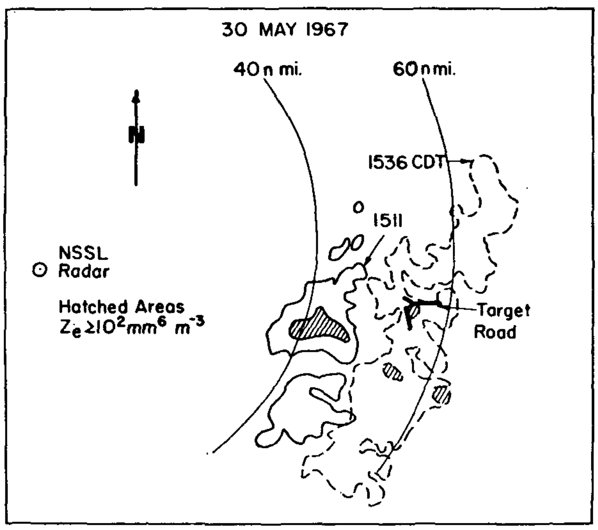

FIG. 3. Sketch of images from two PPI scope photographs (solid and dashed outlines). Limiting contour indicates region of 10 mm^6 m^{-3}. The small intense region near the target road appears to be the tracer-inoculated shower.

FIG. 5. Samplers distributed by the mobile units are plastic yard baskets of 20-inch diameter at the mouth, lined with polyethylene bags. The liner is held by a rubber band which also serves to support the unit against a roadside fence. The samplers are pre-innoculated with 50 ml of 6N HCl to assure acid solution of all tracer indium in the collected sample.

5. Results

The chemical and radioactivation analysis procedures are presented in a companion paper by Gatz *et al.* (1969). Backgrounds of natural and reagent indium were determined by the analysis of samples procured from untagged rain showers (29 samples), and of reagent blank tests in the laboratory. The reagent blanks (16 samples) contributed 1.5 ± 1.5 nanograms (ng) In liter^{-1} according to these tests, and the untagged rain background turned out to be 6 ± 3 ng In liter^{-1}. These figures must then serve as the basic criterion for judging the significance of the In amounts found in the tracer-tagged rain samples.

Fig. 6 shows how the indium concentrations found in the tagged rain compare with those in the untagged rain. All but two of the background (untagged) rain samples contained less than 12 ng In liter^{-1}, the largest number of samples being at the 2–4 ng liter^{-1} level. Half of the tracer-tagged rain samples contained more than 12 ng liter^{-1}, the highest value being 40 ng liter^{-1}.

The In concentrations found in the tracer-rain samples are given as a function of position along the east-west road in Fig. 7 and along the north-south road in Fig. 8. The results of the background study are blocked in. The two distinct levels of In concentration shown in Fig. 7 evidently show significant amounts of the In tracer near the west end of the array as contrasted to natural or background amounts at the east end.

Ordinarily, the concentrations of naturally occurring contaminants in convective showers are high in the initial light rain, decrease to a minimum at or near the rainfall rate maximum or core of the shower, and then increase again in the more stable light rain at the end. This sequence of concentration changes is also reported by Gatz *et al.* (1968) for In in one shower. In the present instance, we find evidence of the tracer In plume in the samples taken along the east-west road by virtue of a strong deviation from the usual scavenging pattern.

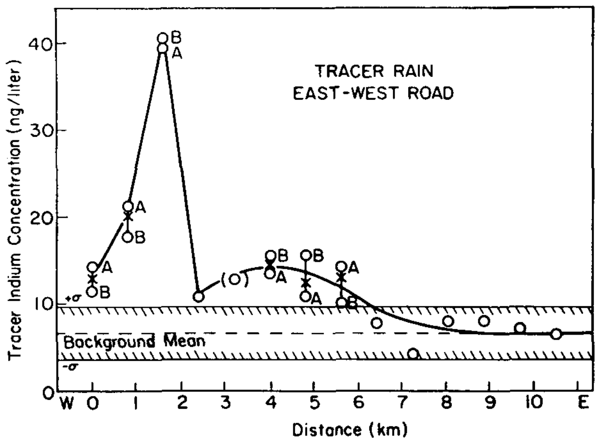

FIG. 7. Variation of indium concentration with distance along the east-west road (U. S. 270). Only the first three samplers were in position to sample throughout the rain shower. Those farther east were all placed after the rain had begun, and they were placed increasingly later with respect to the rain core as the array was extended eastward.

Various considerations enter. One is that only the first three samples (at ~0, 1 and 1.7 km) in Fig. 7 represent the whole shower. All of the other samplers were set out after the rain had begun at the respective stations, and that at ~10.5 km was set definitely after the rainfall climax. Naturally distributed contaminants should occur in moderate to high concentrations in the easternmost samples because these represent the light rain at the end of the shower. The indium concentrations in these approach the background mean. The samples for the interval from 2.5 to 6 km exceed the background mean by about 2σ, but these contain water from the more intense part of the shower. If the indium present were a natural contamination, it should be lower in concentration in these samples than in those farther east. This, in addition to the significant concentration maximum at the third station (~1.7 km), tends to

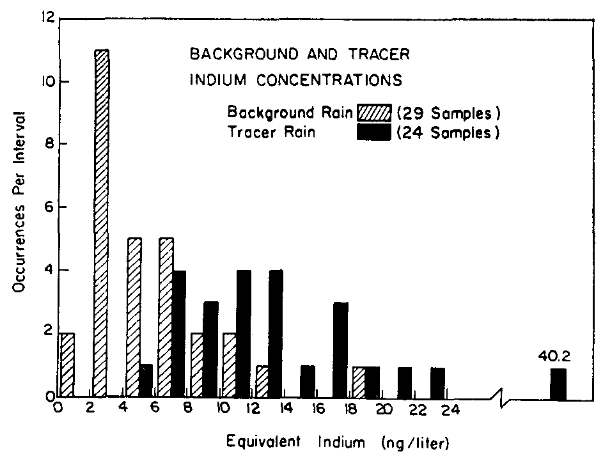

FIG. 6. Frequencies of occurrence of different concentrations of indium in samples from tracer-tagged and background (untagged) rain showers.

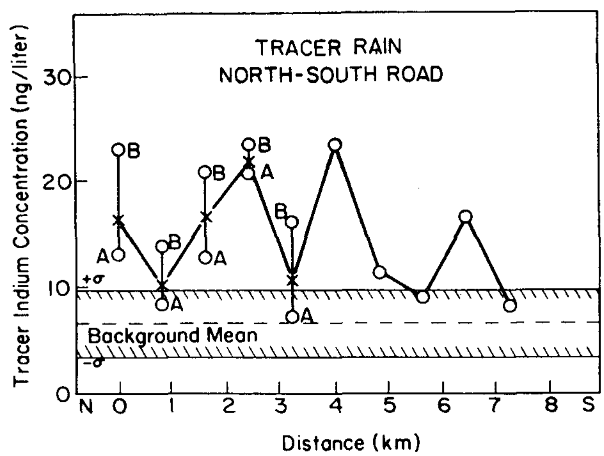

FIG. 8. Variation of indium concentration with distance along the north-south road (state route 48). Rain began just prior to setting the third sampler (at ~1.7 km).

support the conclusion that indium from the tracer plume has indeed been found in these samples.

Although the results from the north-south road array (Fig. 8) are less systematic than those of Fig. 7, the evidence of these data also favors the hypothesis that tracer indium was collected in the samples and is observable considerably (3σ) above background.

6. Conclusions

We feel that this pilot experiment for the first time shows that it is feasible to place a finely divided tracer material into a convective rain-generating system and to identify and measure quantities of the tracer in rain samples collected at the ground.

Further, the usefulness of indium, specifically as a trace element, has been shown, and is largely attributable to its properties favorable for neutron activation analysis (sensitivity routinely 10^{-10} gm $\pm$ 5%), and its low natural atmospheric background.

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