NOAA TECHNICAL MEMORANDUM NWS CR-60

METEOROLOGICAL EFFECTS ON THE DRIFT OF CHEMICAL SPRAYS

Jerry D. Hill
WSO/AG Lexington, Kentucky

Scientific Services Division
Central Region Headquarters
July 1976

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / National Weather Service

METEOROLOGICAL EFFECTS ON THE DRIFT OF CHEMICAL SPRAYS

Jerry D. Hill
Advisory Agricultural Meteorologist
National Weather Service Office for
Agriculture
Lexington, Kentucky

Introduction

Chemicals for pest control are finding widespread use throughout many phases of America's agricultural production and, also, in some additional applications such as reducing populations of mosquitoes or undesirable bird species. Many spray materials are available which have a high degree of effectiveness on certain diseases, weeds, and insects affecting a particular crop but may be totally unsuited for other crops; in fact, chemical residues may render a different crop unmarketable or may destroy it completely. On the other hand, some sprays require particular care because of their toxic effect on humans.

Concern over the environment has caused the Federal Environmental Protection Agency and many similar state agencies to develop extensive regulatory statutes which control pesticide use. Applicators must be licensed, and even individual farmers must receive special training. Sophisticated laboratory equipment is available now which can detect even the smallest residue of an undesirable chemical and makes enforcement of the regulations more fesible than ever before.

The drift of chemical sprays out of the intended area and onto another area is a serious problem that every applicator faces. It involves several factors, particularly the meteorological aspects. While the meteorological situation does not totally determine the amount of drift, the influences are similar to air pollution, playing such a major role that all meteorologists should be familiar with their effect. This paper will describe some of the ways the drift and deposition of pesticides occurs but, unfortunately, cannot establish limiting meteorological criteria for making those "spray" or "don't spray" decisions. Its value should be to alert forecasters to the complexity of the problem so they will not be prone to answer requests for crop spraying forecasts with oversimplified judgements.

Factors Affecting Drift

Drop Size

Droplets dispensed by a sprayer are generally in the size range of 25 to 500 microns (10^{-6}m) in diameter, and equipment may be purchased which releases different sizes for varied applications. In recent years there has been a tendency, especially for aerial applicators, to select ultra-low-volume equipment which uses small amounts of chemical dispensed as many very tiny drops below 100 microns. The use of smaller droplets increases the potential for drift.

The spray material is dispensed under pressure through the nozzle, but the density of the air is sufficient to slow the droplets within inches. From that point, they are moved around by gravity and wind currents. If the air were complete still the tiny particles would fall at a terminal velocity. Stoke's Law, which states that the terminal velocity is proportional to the square of the drop radius, holds for motion in still air when the diameter of the sphere is less than 80 microns. For larger droplets the terminal velocities are well-known and can be found tabulated in the Smithsonian Meteorological Tables.

It may be easier to comprehend the drop sizes involved if they are compared with characteristic types of precipitation or hydrometeors. Drizzle is considered to have a droplet diameter of 100 to 400 microns, mist ranges from 50 to 100, and fog from 10 to 50.

The terminal velocity of large drizzle droplets 400 microns in diameter is about 150 cm/sec, but for those 25 microns in diameter, typical of fog, the fall velocity is only 1 cm/sec. For some typical drop diameters, the time required to settle a distance of one meter has been calculated (1) and is shown in Table 1.

Table 1. Settling time from a height of 1m.

Droplet diameter	Time
200 microns	1.4 seconds
100	4
80	6
70	9
50	14

Droplets of 200 microns or more have little drift potential because they fall rapidly, but the smaller sizes remain aloft long enough to be carried substantial distances by even a gentle wind. Sample calculations were made (1) to determine how far droplets would be carried by a 3 mph wind if released from a height of 10 feet and these data are shown in Table 2.

Table 2. Drift Potential in a 3 mph wind.

Droplet diameter	Distance carried while falling 10 feet
400 microns	8.5 feet
150	22.0
100	48.0
50	178
20	0.21 mile

Chemicals used as pesticides are normally available in a highly concentrated form which is then mixed with water as it is dispensed. The droplets consist of both water and the non-volatile chemical phase. When these are sprayed into the air the water begins to evaporate at a rate determined by the temperature and relative humidity of the surroundings. At a temperature of 80°F and a relative humidity of 50 percent, a 200-micron drop of water will evaporate in 56 seconds. Under the same circumstances, a 70-micron drop will evaporate in 7 seconds, less time than is required for the drop to settle 1 meter.

A 100-micron droplet containing 1 1/2 percent involatile pesticide reduces to a 25 micron drop. If the solution contains 4 percent involatile material its final size is 35 microns. To decrease the evaporation and the increased drift potential, oil or an emulsifier is often added to the solution.

Equipment used

Several different types of spray equipment are available, depending on the nature of the material to be sprayed, area to be covered, and crop to be treated. Some produce a downward-directed spray immediately above the crop canopy, while others produce a fog more suitable to cover fruit trees. The emission height of downward-directed sprays may range from only inches for a sprayer mounted on a tractor to several feet for an aircraft.

The selection of a sprayer or a nozzle may be made from published specifications where the manufacturer has already determined the mean diameter of the droplets it will produce. The advertised size of the drops is only the mean, and the applicator can expect some deviations from that. Even though the mean droplet size desired may be large enough to minimize drift potential, there will be a number of them produced which are smaller and more susceptible to being carried away from the field.

Tests (3) of a commercial sprayer which utilizes a porous, sintered metal sleeve driven by a high-speed electric motor revealed the distribution of drop sizes for several different-sized sleeve openings which were available. Figure 1 shows the sizes which were attempted and the final distribution achieved.

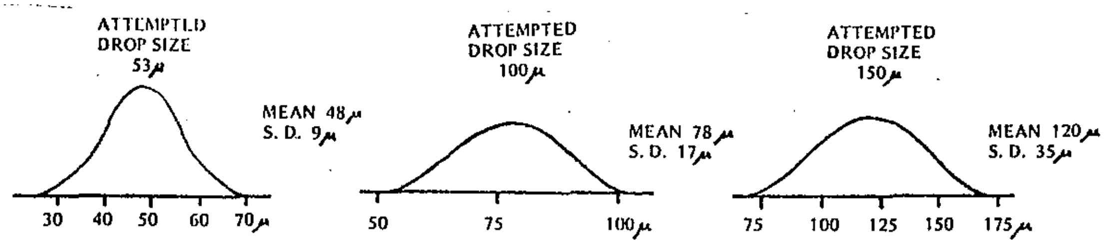


Fig. 1. Attempted and observed droplet spectra.

While there may be a significant number of very tiny droplets produced by all equipment, it should be noted that they dispense only a small portion of the active chemicals. The volume of a sphere varies with the cube of the radius so a 60-micron diameter drop carries less than 1/3rd the volume of a 90-micron drop. That can be an advantage where drift is a concern because the amount of active material leaving the field may be smaller than anticipated and its contamination effect can be minimized by dispersing the material as widely as possible under very turbulent weather conditions.

Meteorological Influences

The assumptions about terminal fall velocities are based on the absence of any upward or downward moving air currents. This is a serious oversimplification since there are always turbulent fluctuations of the wind, even on what might seem to be a very calm day. These turbulent motions in the layer of air nearest the ground are induced by both the horizontal wind shear and buoyancy caused by heating of the ground. Figure 2 shows how chaotic some of these motions can become.

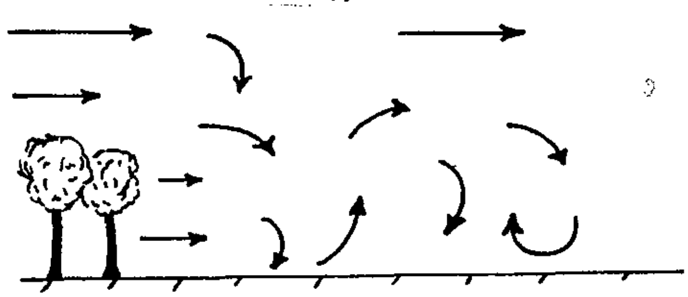
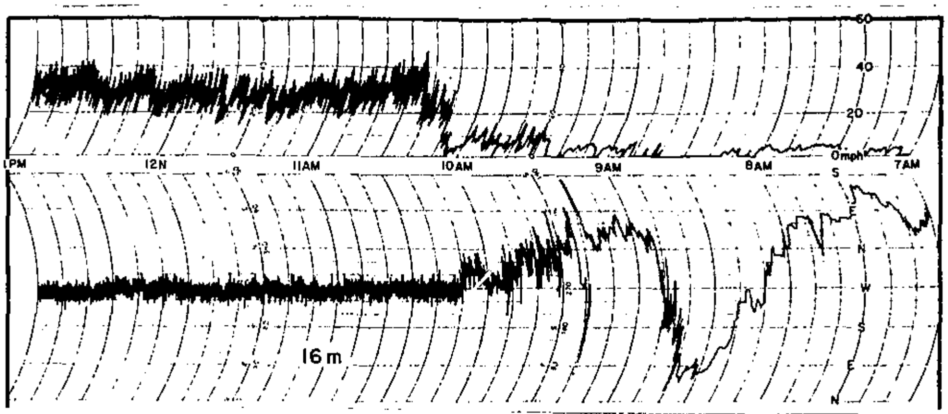


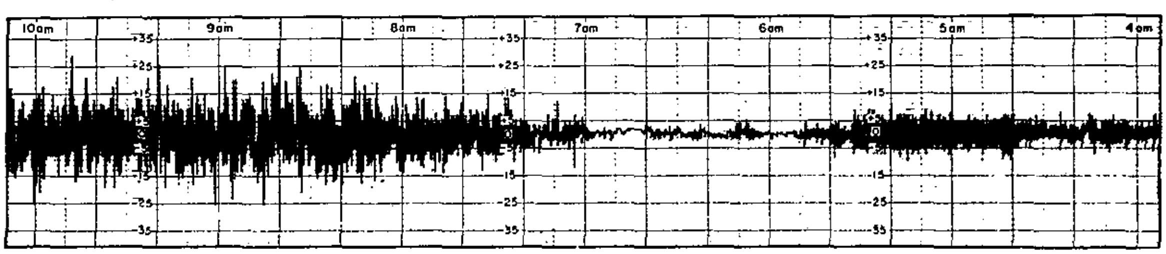
Fig. 2. Turbulent wind structure near the ground during the day.

When nearly adiabatic or superadiabatic lapse rates develop near the ground, eddies are formed in the motions of the air, causing considerable fluctuation in the wind. Winds may be gusty during midday and, although the direction follows the established gradient, the vane might actually be varying rapidly within a 20-degree or so sector. A vertically-mounted vane which measures the up-and-down components of the wind direction would show deviations of up to 25 degrees either side of the horizontal position during these unstable periods.

Observations of both horizontal and vertical wind direction have been collected (4) and are shown in Figure 3. Although they are not from identical sites, they do show very well how the transition takes place from stable to unstable conditions a short time after sunrise as the ground begins to warm.



Horizontal Wind Speed and Direction at 16m.



Example of a vertical wind-direction trace (chart speed, 3 in./hr). The bivane sensor was mounted 10 m above the surface.

Figure 3. Variations of horizontal and vertical wind direction under varying stability.

When these two extreme types of weather conditons prevail there is a characteristic mixing of smoke or spray materials. As an example, a plume of smoke on a sunny afternoon would appear to loop upwards then dip to the ground as the vertical wind currents dispersed it through a large layer of air. In the early morning, while the air is stable, the smoke would be drawn into a long plume and held aloft while it drifted away. These typical patterns are contrasted in Figure 4.

Figure 4.

Several different methods are available for estimating the instability of the lower atmosphere, using available meteorological data. Perhaps the most commonly used is Richardson's Number which is defined as:

$$Ri = \frac{g}{T} \frac{\left(\frac{\partial T}{\partial z} - \Gamma\right)}{(\partial \bar{U}/\partial z)^2}$$

where: g is the acceleration of gravity

T is the air temperature

$\frac{\partial T}{\partial z}$ is the existing lapse rate in the surrounding air

Γ is the dry adiabatic lapse rate

$\partial \bar{U}/\partial z$ is the gradient in the vertical of the mean horizontal wind

Richardson's Number is directly proportional to the rate of consumption of turbulent energy by buoyant forces and inversely proportional to the production of turbulent energy by wind shear. Superadiabatic lapse rates produce negative values of the number which imply greater turbulence. Greater wind shear dampens the buoyancy and produces a smaller absolute value.

As a simpler way to quantify the magnitude of the turbulent forces, some investigators have defined a Stability Ratio (SR) which is calculated as:

$$SR = \frac{T\ \text{upper} - T\ \text{lower}}{U^2}\ 10^5$$

where T is the air temperature measured at two levels near the ground and U is the average wind speed at a point between. The upper and lower levels where the temperature is measured vary among experimenters, but some typical values are 32 and 8 feet or 28 and 6 feet. Like the Richardson Number, the Stability Ratio becomes negative with larger absolute value as the temperature nearest the ground increases and produces greater buoyant forces.

In experiments at the University of California (5), to study pesticide residues, the stability ratio was calculated while both the horizontal and vertical wind speeds were measured. The data from four separate cases are shown in Table 3.

Table 3. Stability Ratio and wind speed observations

Mean Stability Ratio	Mean Horizontal Wind	Mean Vertical Wind
- 4.8	2.5 mph	+ 1.7 cm/sec
- 1.2	5.7	+ 4.0
- 2.2	4.6	+ 5.2
- 0.74	5.8	+2.7

The implications of the magnitude of the vertical wind speeds can be understood by considering the fall velocity of the various sized droplets. These are shown in Table 4.

Table 4. Terminal drop velocities

drop size	terminal velocity
400 microns	162 cm/sec
100	27
50	8
25	1
10	.3

The typical mean vertical wind speeds on an unstable day exceed the terminal velocity of all droplets smaller than about 50 microns. In some cases the vertical speeds have been noted to exceed 10 cm/sec which would allow even larger droplets to be suspended or carried aloft.

Implications of Meteorological Effects

Meteorological conditions are continually changing as a day progresses from early morning to evening, and it is particularly difficult to consider even idealized conditions. Perhaps it is best to consider the extreme cases and recall that actual results may lie somewhere between.

The unstable case is normally a combination of sizable vertical eddies along with horizontal speeds of 10 to 25 knots. The downward-directed motions of the air alternate with the upward motions to create the wavering plume which disperses the spray through a sizable depth of air. The downward motions actually transport the spray into contact with the leaf surface more readily than gravity alone. The upward motions though may exceed the fall velocity of the droplets and carry them to a height from which they will drift longer distances. The net effect on a level field is to mix the suspended chemical through a greater volume of air and reduce the concentration levels deposited outside the field.

Stable or neutral weather conditions are characterized by horizontal stability and the absence of downward transport to carry the material onto the leaves. During the time required for the droplets to settle to the ground, even a light horizontal wind may cause significant numbers to drift away. Table 2 indicates that a 3-mph wind would carry a 20-micron drop nearly a quarter of a mile during the time required for it to fall 3 meters. The lack of vertical mixing under these conditions allows the concentration of the chemical to remain high in the center of the spray plume.

Research conducted to determine the drift under varying low-level stability has revealed that residues found outside the target area are greatest when the lapse rate is stable. In a study several years ago (5) DDT was sprayed onto a field of cotton and the residue measured on a nearby field of alfalfa. The application was made from a Stearman aircraft flying 1 to 4 feet above the crop. Figure 5 shows the residues which were found.

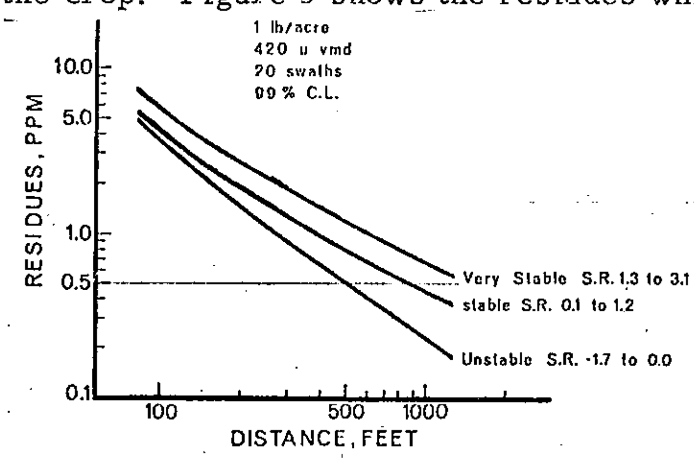


Fig. 5.

Micro-weather Effects on Drift Residues Found Outside of the Target Area.

The dotted line at 0.5 PPM represents the legal tolerance which then existed in California for DDT residues on dry alfalfa hay. Just how small this quantity is can be understood when one considers that it is the equivalent of one tablespoon of technical DDT over 20 acres of alfalfa. The notable results of the experiment are that the residues found 500 feet or more outside the target area were within the allowable tolerance when the lapse rate was slightly unstable. The very stable lapse rates allowed high concentrations to drift farther downwind.

The results of this experiment were substantiated in a different trial (2) where agricultural chemicals were dispensed from a tractor moving along the ground. Sampling stations established up to 1000 feet downwind measured the amount of material landing outside the swath covered by the sprayer. Figure 6 shows how the deposits outside the swath increased during light winds and stable conditions.

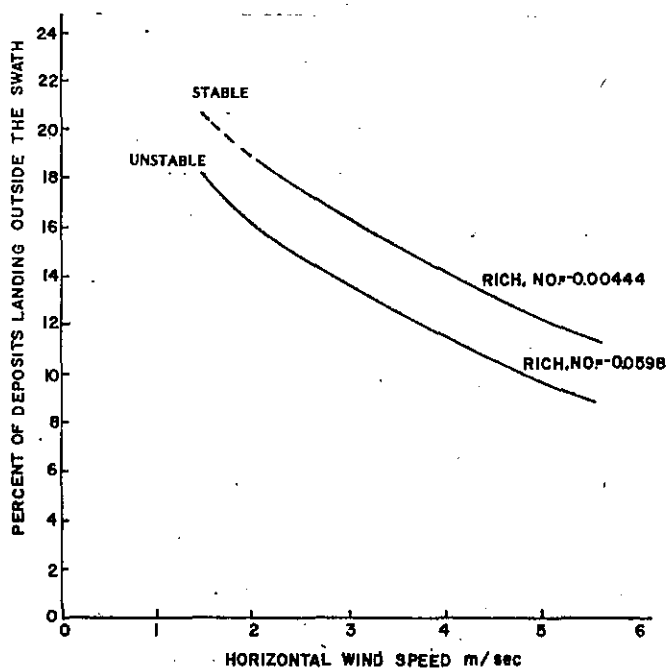


Fig. 6. Decrease of drift deposits with increasing wind and turbulence.

The decreased drift detected at higher wind speeds is attributed by the investigators to greater evaporation of the droplets under those conditions.

Summary and Recommendations

The meteorologist finds himself in a difficult position regarding spray applications. The applicator has already selected his equipment with its intrinsic characteristics and may have a substantial acreage to treat - so much that the job might require an entire day or several days. The limitation on times to spray may be impractical, and he may only be interested in a forecast of conditions which might cause extreme drift. His final decision will certainly be influenced by the type of chemical being sprayed and whether it is toxic to other crops, livestock, or humans.

The operator must consider whether he is using all of the techniques available to minimize drift. The height of the sprayer should be as low to the crop surface as possible to produce needed coverage, and a cowling of some type around the spray nozzle will reduce the number of errant droplets. Certainly the addition of oil or an emulsifier to his mixture will reduce the drift potential related to rapid evaporation of the droplets. Equipment which is designed to produce droplets with a small diameter, especially less than 100 micron, has the most serious drift potential.

From a meteorological standpoint there are several indications of conditions when high concentrations of pesticides may drift out of the target area:

1. Obvious windy periods with strong horizontal winds increase the transport of chemicals out of the field.

2. Early morning or evening periods when low-level stability exists are times when small droplets can remain suspended for long periods and drift even in light winds.

3. Mid-afternoon periods of low humidity are favorable for the water in the spray droplet to evaporate and produce smaller drops with greater drift potential.

The conclusions of several studies indicate that a little turbulence can help to minimize contamination outside of the field. It should be accompanied by light winds though, which makes the ideal condition a transient combination most likely only for a short time in the morning hours.

The almost continuous motions of the atmosphere make it practically impossible to have conditions when spray drift is non-existent. Each possible set of weather conditions provides some factor which is favorable for drift. In addition, these factors change from one hour to the next as temperatures, cloudiness, and wind vary. They'll also change from one field to another depending on how the wind may blow around trees or hills and produce local eddies. The problem of drift is a challenge to the meteorologist but the proper interpretation of appropriate weather information can help the applicator obtain the maximum effectiveness from his chemicals while minimizing contamination of our environment.

References

1. Canada Committee on Agricultural Meteorology. 1971: Meteorological Aspects of Pollution in Relation to Agricultural Pesticides. Research Branch Canada Department of Agriculture. Ottawa, Ontario. 70 pp.

2. Goering, C.E. and B.J. Butler. 1975: Paired Field Studies of Herbicide Drift. Trans of the ASAE. 18:27-34

3. Threadgill, E.D. and D.B. Smith. 1971: Effects of Physical and Meteorological Parameters on the Drift of Controlled size ULV Droplets. ASAE Paper No 71-663. ASAE, St. Joseph, MI. 49085.

4. U.S. Atomic Energy Commission. 1968: Meteorology and Atomic Energy 1968. USAEC Division of Technical Information Extension, Oak Ridge, TN. 445 pp.

5. Yates, W.E., N.B. Akesson, and H.H. Coutts. 1966: Evaluation of Drift Residues from Aerial Applications. Trans. of the ASAE. 9: 389-397.