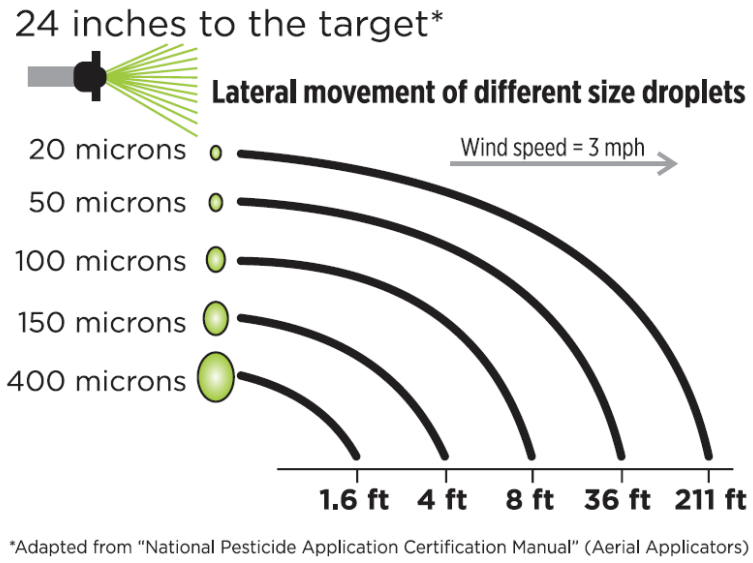
Air Temperature Inversions

Since the 1990's, industry and the U.S. EPA have recognized that off-target movement of pesticides can be amplified by air temperature inversions. Thus, pesticide labeling often contains cautionary language regarding making applications when an air temperature inversion is or will be in place. This language has evolved in recent years to strong prohibitions regarding applications of certain pesticides during air temperature inversions. Recently introduced, low volatility formulations of dicamba, used in over the top applications to tolerant soybean varieties, are now specifying prohibitions of applications from two hours before sunset to one hour after sunrise as a means to further reduce the impact of air temperature inversions.

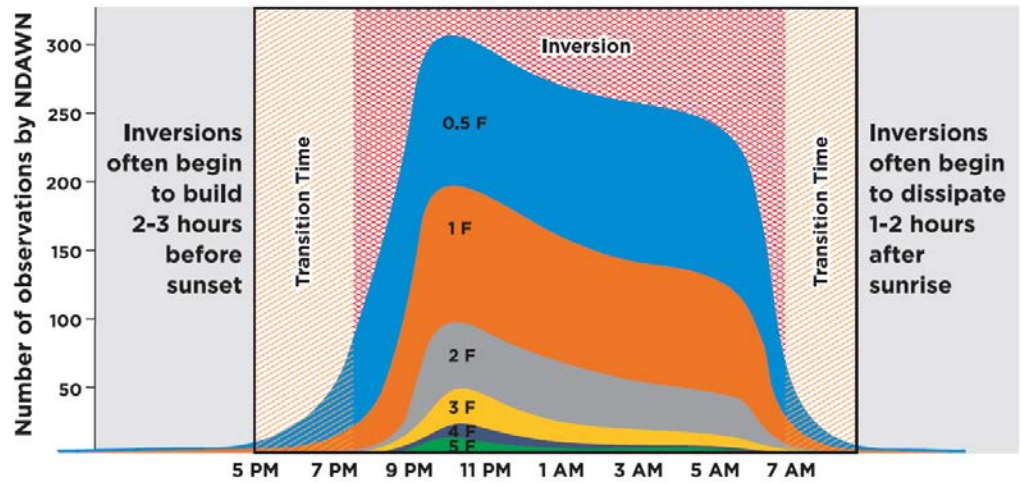
Air temperature inversions are an environmental phenomenon that have long been recognized to adversely impact the deposition of fine spray drops. The following graphic demonstrates that fine spray drops reach the target very slowly and this makes them more susceptible to lateral movement off target in light winds. Especially when they encounter dense, cooler air, near the ground, in an air temperature inversion.



Dense air suspends fine spray drops, and small ones can move large distances in low-wind conditions.

In addition, air stability near the earth surface allows for the accumulation of volatile pesticide molecules which may easily move down range in a light breeze to non-target sites. When this happens, sensitive plants and animals may be adversely impacted.

Multiple site observations of air temperature inversions have been collected in North Dakota since 2017. The following graphic from 2017 demonstrates that air temperature inversion begin to build two to three hours before sunset and then begin to dissipate 30 to 120 minutes after sunrise.



This is an accumulation of inversion data from 11 NDAWN locations in North Dakota during June, July and August 2017. This figure indicates that an inversion will begin late in the day before sunset, continue all night and begin to dissipate soon after sunrise, when the sun starts to heat the Earth.

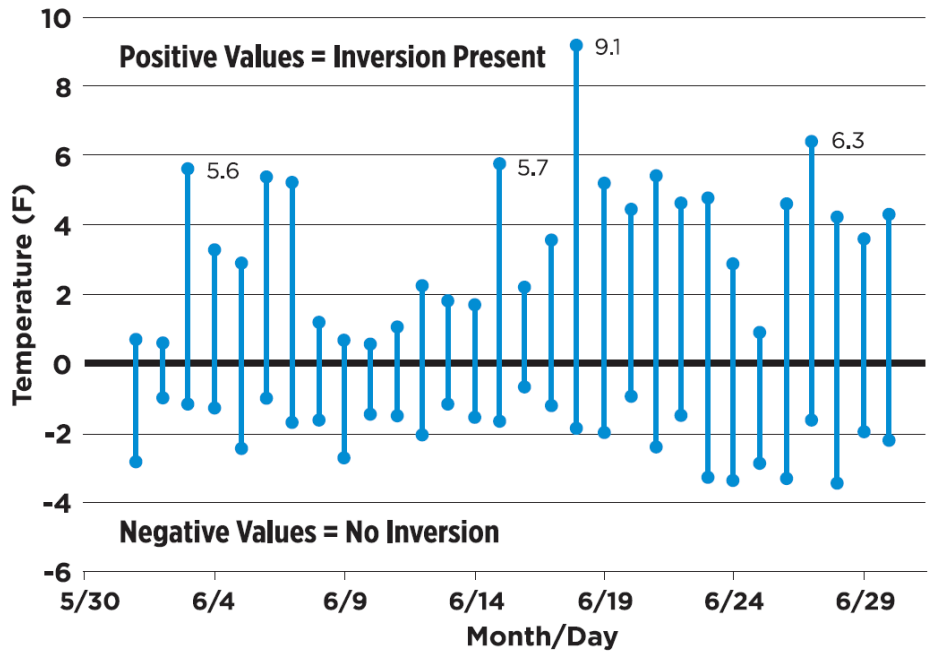
While air temperature inversions are typically associated with wind speeds of zero to three miles per hour, our observations indicate that significant inversion conditions can exist at much greater speeds. See the following graphic:

Wind Speed (mph)	0.5	1.0	1.5	2.0	2.5	3.0	3.5
15	0.07%	0.00%					
14	0.13%	0.01%					
13	0.14%	0.02%					
12	0.19%	0.02%	0.00%				
11	0.30%	0.02%	0.01%	0.00%			
10	0.50%	0.08%	0.00%	0.00%			
9	0.92%	0.09%	0.02%	0.01%			
8	1.37%	0.19%	0.05%	0.02%	0.00%	0.00%	
7	2.15%	0.38%	0.09%	0.03%	0.01%	0.01%	
6	3.21%	0.76%	0.24%	0.09%	0.09%	0.01%	0.00%
5	4.46%	1.47%	0.49%	0.28%	0.09%	0.04%	0.01%
4	5.64%	2.83%	1.24%	0.78%	0.47%	0.22%	0.11%
3	6.66%	4.80%	2.79%	1.82%	1.10%	0.71%	0.39%
2	6.58%	5.60%	3.74%	2.21%	1.35%	0.86%	0.40%
1	3.97%	4.09%	3.04%	1.91%	1.21%	0.70%	0.40%
0	2.93%	3.57%	2.95%	2.04%	1.37%	0.93%	0.52%

Inversion (F)

Significant inversion conditions can exist in wind speeds of 6 mph or more. This chart shows the percent of time that several NDAWN stations indicated an air temperature inversion. For example, 4.80% of the time an inversion of 1 degree existed with a 3 mph breeze.

Air temperature inversions can be measured on most 24 hour days. The observations from 2018 at Grafton, North Dakota illustrates this. However, there is wide variation regarding the intensity of inversions from day to day. Calm atmospheric conditions are usually associated with the most intense inversion observations.



Daily minimum and maximum inversion temperatures, Grafton, N.D., June 2018. Temperature difference was measured at 1 meter and 3 meters (F) above ground level at the NDAWN station. Details for June 2018 is available at: https://ndawn.ndsu.nodak.edu/station-info.html?station=77

A comprehensive explanation of air temperature inversions and their potential impact on pesticides can be found in the NDSU publication, “Air Temperature Inversions Causes, Characteristics and Potential Effects on Pesticide Spray Drift (AE1705 (Revised October 2019)). The publication is available on-line at: https://tinyurl.com/NDSU-Inversion-AE1705

Pesticide applicators now have excellent tools for identifying air temperature inversions. In North Dakota and in portions of Minnesota and Montana, NDSU operates the NDAWN Mesonet Weather System. Selected stations (131 as of October 2019) monitor actual air temperature inversion intensity by comparing air temperature at three meters and at one meter. Observations and recordings are made every five minutes and reported on the world wide web at: https://ndawn.ndsu.nodak.edu An Android and iPad app is available for reporting station readings and to send alerts when an inversion observation occurs. Details can be found here: https://www.ndsu.edu/ndscoblog/?p=4031 Finally, Innoquest, a developer of application spray equipment accessories makes a hand held tool for measuring air temperature inversions. You can find more information on their device here: https://innoquestinc.com

Delta T: A Tool for Pesticide Application Decision Making

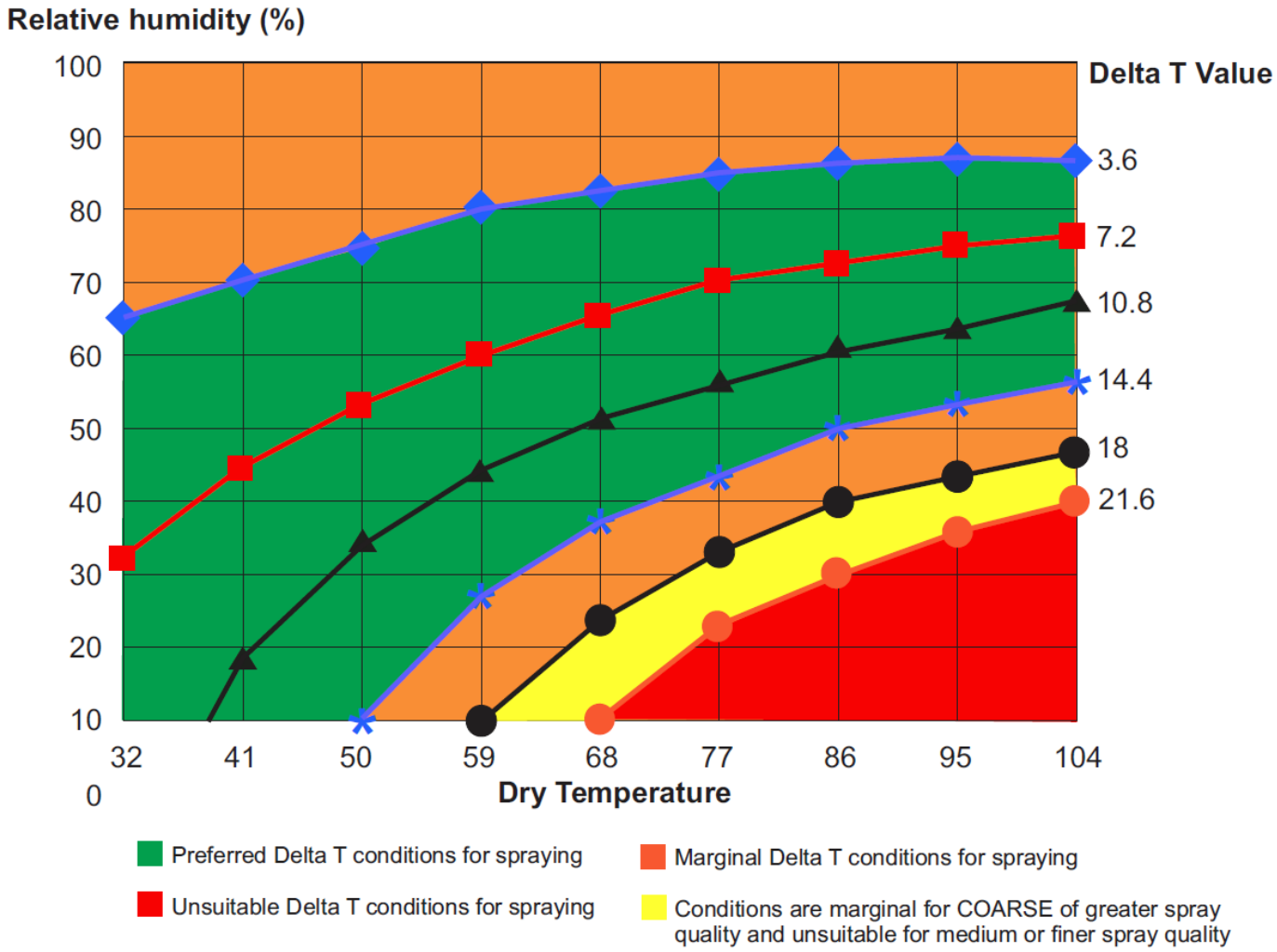
Delta T is the temperature difference between a dry bulb (air temperature sensor exposed directly to the air) and a wet bulb (air temperature sensor enclosed in wetted material so that water is constantly evaporating from it and cooling the bulb). The higher the Delta T value, the drier the atmosphere is with greater potential to evaporate spray drops.

Delta T is the primary method by which applicators in Australia decide when and how to apply pesticides to improve efficacy and reduce spray drift. It originated in the early 1990's. It was designed in the era when the primary spray nozzle was a flat fan. Because these nozzles produce a relatively high proportion of fine spray drops, there was widespread concern, especially in the drier and hotter parts of Australia, that significant evaporation of these fine drops would lead to coverage/efficacy issues as well as increased spray drift. The Australian's also use relatively low Delta T values as an indication that an air temperature inversion is likely occurring and/or the humidity is so high that fine spray drops would have a tendency to move further down range.

The Delta T concept has gained some adoption in the arid portions of Western Canada. Weather instrumentation manufacturers in North America have also built a Delta T value into their devices. Kestrel Meters and Weather Flow both make instruments that report a Delta T value. In the United States, Delta T has not been widely used. It is not part of standard pesticide application curricula.

Figure 1. is a graphic depicting how the Delta T value changes relative to humidity and temperature. Delta T is reported on the right side of this graphic. It is expressed in degrees F. On the bottom of the graphic, the legend describes whether it is acceptable or not to spray, what is optimum, and when are the conditions marginal and under what circumstances. Temperatures reported in the chart are not rounded to customary five or ten degree increments. That is because this chart was originally created in degrees Celsius. In order to maintain the integrity of the curves, Fahrenheit degrees have simply been substituted to replace the Celsius temperatures.

Figure 1. Delta T values for determining when to make pesticide applications. This graphic was created by NDSU Ag Communications.



A typical flat fan spray nozzle set at 40 psi will produce 30% or more fine spray drops. All those drops are likely to evaporate before they hit the target with a Delta T value of 18 or more. That will result in coverage and efficacy issues. Further, because ALL the spray drops are shrinking because of evaporation, more and more of the spray will be subjected to wind movement and drift. The impact of evaporation on a spray application can be partially offset by increasing droplet size. Coarse or greater spray quality drops, those often produced by an Air Induction or a Turbo Teejet Induction nozzle, can be used up to a Delta T of 21.6. But after that, the evaporation rate becomes so problematic that applications are no longer recommended.

Table 1. Sample weather variables from selected NDAWN Stations . The Delta T value is reported in green because the estimated Delta T is less than 14.4. degrees F but more than 3.6 degrees F. This is in the preferred range for spraying.

Station	Ag District	Last Updated	Current							
			Air Temp	Wind Dir	Wind Speed	Peak Gust	Rel Hum	Dew Point Temp	Est. Wet-bulb Temp	Est. ΔT
Ada 1N	MN-NW	16 May 15:20 CDT	58°	N	15 mph	19 mph	47 %	38°	48°	10°
Adams 5N	ND-NE	16 May 15:20 CDT	53°	N	12 mph	20 mph	41 %	30°	43°	10°
Alamo 2S	ND-NW	16 May 15:20 CDT	57°	NE	11 mph	16 mph	31 %	27°	43°	14°
Baker 1N	ND-NC	16 May 15:20 CDT	55°	NNE	6 mph	12 mph	36 %	28°	43°	12°
Beach 9S	ND-SW	16 May 15:20 CDT	55°	E	14 mph	19 mph	55 %	39°	47°	8°
Becker 1W	MN-C	16 May 15:20 CDT	73°	N	15 mph	20 mph	46 %	51°	60°	13°
Berthold 5NW	ND-NW	16 May 15:20 CDT	55°	NE	8 mph	15 mph	33 %	27°	43°	13°
Bottineau 14W	ND-NC	16 May 15:20 CDT	58°	NNE	12 mph	18 mph	29 %	25°	44°	14°
Bowbells 1N	ND-NW	16 May 15:20 CDT	55°	NE	6 mph	10 mph	33 %	26°	43°	13°
Bowman 4W	ND-SW	16 May 15:20 CDT	55°	ENE	14 mph	19 mph	61 %	41°	48°	7°
Brampton 2WSW	ND-SE	16 May 15:20 CDT	58°	NNE	13 mph	19 mph	57 %	43°	50°	8°
Brorson 5NW	MT-NE	16 May 15:20 CDT	59°	ENE	11 mph	17 mph	37 %	33°	46°	13°
Campbell 3SE	MN-WC	16 May 15:20 CDT	58°	N	19 mph	25 mph	62 %	46°	51°	7°
Cando 2SE	ND-NE	16 May 15:20 CDT	54°	NNW	10 mph	15 mph	46 %	34°	45°	10°
Carrington 4N	ND-C	16 May 15:20 CDT	57°	NNE	13 mph	20 mph	31 %	27°	43°	13°

Just like other weather variables, Delta T will change throughout the day. Generally, in the early morning hours, the value will be low, but as the day warms, the number will rise. As evening and night sets in, the numbers will fall again. In North Dakota, Delta T values will generally be higher in the SW and lower in the NE region of the state (relatively warmer and drier climate versus a cooler and higher precipitation one).

Delta T is an excellent way to understand the impact of temperature and humidity on a spray drop. Delta T values are reported every five minutes through the North Dakota Agriculture Weather Network (NDAWN). They are located on the world wide web at: https://ndawn.org