WEATHER ESSENTIALS

FOR PESTICIDE APPLICATION

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By Graeme Tepper

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Introduction

Weather essentials for pesticide application aims to help those applying pesticides to understand, observe, interpret and react appropriately to changing weather conditions to ensure efficient and effective pest control while mitigating drift.

This publication provides a practical and visual guide to all weather conditions impacting pesticide applications. It places emphasis on atmospheric stability, local wind flows, turbulence, evaporation of droplets, volatilisation and dispersion, which together determine the fate of pesticides in the atmosphere and downwind concentrations impacting recipients.

Drift is invisible and yet it continues to cause millions of dollars of damage to crops and products each year. Much of the damage has been attributed to spraying during hazardous inversions, rather than spraying in conditions that are too hot or too windy.

Hazardous inversions have only recently been defined and methods to detect and forecast them specified (Grace and Tepper 2021). Some conditions of hazardous inversions described here will surprise because they go against traditionally held beliefs that inversions only occur in near-calm conditions and clear skies.

Indications of strongly stable and hazardous conditions with aerosols concentrated in thin layers. Photo: Nicola Cottee

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Off-target movement of pesticides

Large droplets will not drift very far; however, small droplets, tiny particles (remnants of evaporation) and vapours can drift for many kilometres at high concentrations within hazardous inversions, and at lower concentrations through the wider atmosphere when thermals are active.

Drift initiation

The amount of chemical able to drift is first dictated by the operator's choice of tank mix, the total amount of product used, and operating practices including nozzle, pressure, boom height and speed across the paddock.

The initial 'driftable' percentage may increase if the initial spray sheet that forms the droplets is unduly shattered or deformed, or where the droplets are lifted above the release height by wake effects of the machine, wind turbulence and thermals. The lifting of droplets extends the evaporation time and therefore reduces the size of otherwise larger droplets down to a driftable size.

High booms increase drift volume by extending the time droplets are affected by evaporation, winds and thermal lift. Increasing height from 50 centimetres to 70cm can increase drift potential by up to four times, and by up to 10 times if raised to one metre above the target.

Wake effects and thermally induced vertical winds can easily lift 200-micron (µm) droplets, expose them to extended periods of evaporation and ultimately reduce them to sizes that readily drift.

Taking steps to reduce droplet 'air time' will reduce atmospheric effects and therefore reduce drift risk.

Fast spraying speeds increase wake effects and air movement across the nozzle, which can cause smaller droplets to escape from the spray pattern and be prone to rapid evaporation, thereby increasing the risk of spray drift.

What drifts?

What drifts depends initially on operating factors and thereafter on the atmospheric conditions encountered. Atmospheric conditions of stability, wind, air currents, temperature and humidity within the first few tens of metres of the surface will dictate impacts across local regions. Atmospheric conditions within the free troposphere (above about 700m) will dictate long-term residence in the atmosphere and transport out of the local region.

1 Droplets less than 150µm are highly susceptible to being carried away by the wind and to rapidly evaporate. Droplets larger than 200µm should, in theory, make it to the target. However, droplets even larger than 200µm can rapidly reduce in size and drift when not applied carefully and/or when they are exposed to the hot and dry conditions often experienced over sparsely vegetated paddocks in summer.

Droplets and particles either initially released or reduced to 50µm and vapours are unlikely to fall by gravity to the surface. During unstable conditions, such invisible material will disperse throughout the overlying atmosphere and most likely only return to the surface with rainfall (wet deposition). During strongly stable, hazardous inversion conditions, such invisible material will remain suspended at high concentration for long periods in layers close to the surface. Weak turbulent fluctuations can keep material less than 50µm and vapours suspended for long periods near the surface when hazardous inversions exist.

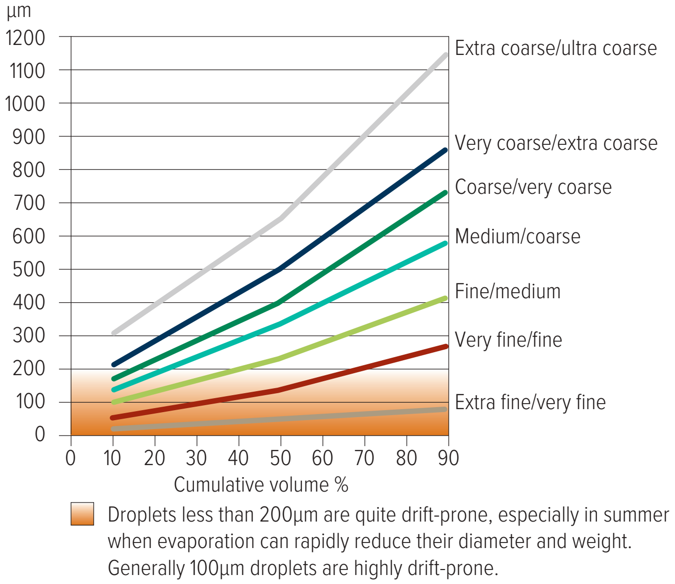
Even small changes in droplet diameter make a big difference to drift potential. Increasing the size from 150µm to 300µm increases weight and volume by eight times. Heavier droplets fall more rapidly and are less affected by air currents, wind and evaporation. Increased droplet volume resists evaporation (larger droplets evaporate much slower than smaller droplets).

2 Vapours can be released from drifting droplets. However, volatilisation from the surface after application is the main concern for vapour drift. Formulation type has a major influence on the potential for volatilisation to occur, with salt-based products generally presenting a much lower risk than ester-based products.

3 Products of evaporation, being either: (1) highly concentrated, very small droplets (the active does not evaporate); (2) 'soggy' crystals of active (most of the carrier has evaporated); or (3) microscopic particles of the active or vapour (all carrier evaporated off) are highly drift-prone as they tend to float about in the air and be carried away by wind and air currents. In unstable conditions the products of near or total evaporation will tend to disperse and therefore dilute with distance from the release point. In strongly stable conditions with laminar wind flow (typical of drainage winds) the products of evaporation or volatilisation remain at quite high concentrations and drift for long distances.

4 A source of drifting pesticides not often considered is the drift associated with host aerosols. Airborne pesticides attached to aerosol droplets and particles of haze, fog, smoke, pollen, dust and salts can remain in the air for extended periods of time. Smog is a good example of pollutants attached to or absorbed into such aerosols.

Figure 1: Spray nozzle classification by droplet spectra example reference graph.



All nozzles will produce a percentage of small droplets capable of moving with the wind or evaporating to sizes highly susceptible to being caught up in air currents. The chart shows that for a nozzle that produces a fine to medium spray quality up to 40 per cent of the spray volume (applied chemical) is in droplets smaller than 200µm, which are highly drift-prone. If operating practices are not optimal and/or weather conditions are windy, hot or dry it is possible to lose more than 40 per cent of total spray volume to the atmosphere.

The 50 per cent value for all spray qualities shown in the above graph is equivalent to the volume median diameter (VMD). A droplet dimension indicating that half of the spray volume is in droplets smaller than this number and half of the spray volume is in droplets larger than this size. Ultimately the problem of small droplets is the high potential for loss of product, loss of pest control and the potential for excessive drift.

Source: Adapted with permission from Asabe Standard S572: Spray nozzle classification by droplet spectra (www.asabe.org/standards/images.aspx). St. Joseph, mich.: American Society of Agricultural and Biological Engineers

Kurrajong trees impacted by low level spray drift while weeds appear to be doing well. Photo: Craig Day

Kurrajong tree fighting to survive after pesticide caused defoliation. Photo: Craig Day

Weather guidelines for pesticide application

Spray when wind is steady and ideally more than 5km/h and up to 15km/h

Very light winds (less than about 5km/h) are often inconsistent in strength and direction. They frequently accompany two of the most adverse spraying conditions: strong thermals and hazardous inversions.

- Thermal activity interrupts the general synoptic wind flow.
- Thermal updrafts have the potential to lift suspended material into the atmosphere; it may later return to the surface in descending air currents.
- When inversions lack turbulence, they trap and concentrate suspended spray materials in layers. The trapped material can be transported at high concentrations for long distances, for example a 5km/h wind can transport material 50km overnight.
- Winds less than 5km/h are highly likely to be variable in direction and should be avoided because the direction of drift may shift about and make buffers unworkable.

  ■ Note: winds of about 5km/h are required for an observer to feel the wind on their face.

Winds greater than 15km/h initiate large turbulent eddies that can pick up and disperse sprayed material over a wide area.

- Even larger droplets may be swept off target and affect nearby environments.
- The majority of smaller droplets will tend to be lifted into the atmosphere and may travel long distances.

Avoid spraying in temperatures above 30°C

As temperature increases:

- droplets evaporate faster;
- turbulence intensity generally increases;
- volatile pesticides on soil and plant surfaces vaporise faster; and
- the potential for thermals to lift airborne pesticides into the atmosphere increases.

Always read the product label and follow all instructions. They may differ from the guidelines in this publication.

Aim to spray when Delta T is between 2 and 10 and not greater than 12

Delta T is an indicator of the evaporation rate for water droplets. Larger droplets evaporate more slowly than small droplets at the same Delta T. This is because the exposed surface compared to volume is greater for small droplets. Droplet survival reduces as Delta T increases.

A stable atmosphere with an inversion and Delta T less than 2 – conditions conducive to high concentrations of small droplets remaining airborne for long periods of time.

Photo: Frank Taylor

An indicator of unstable conditions – cumulus clouds.

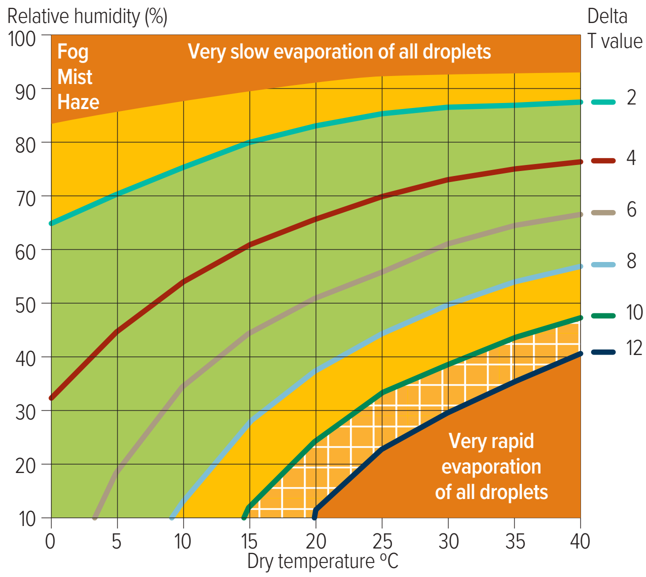
Photo: Graeme Tepper

- A Delta T less than 2 indicates a very moist atmosphere. The relative humidity will be greater than 80 per cent at temperatures greater than 15°C. This can extend the life of small airborne droplets and increase the potential for fine droplets to drift long distances when surface temperature inversions exist.
- A Delta T greater than 8 indicates rapid evaporation of the aqueous component of droplets. In such conditions, the amount of product reaching the target is compromised. An operator needs to decide whether to stop spraying or to continue using a larger droplet size and higher water rate.

Do not spray when hazardous inversion conditions exist

Hazardous inversions lack turbulence and cause high concentrations of airborne pesticides to be transported close to the surface by wind speeds most commonly ranging from 2km/h to 11km/h with occasional speeds up to 15km/h.

Figure 2: The relationship of Delta T to relative humidity and temperature. A common spray guideline is to spray when Delta T is between 2 and 10, with caution below 2 or above 10.



For the estimation of evaporation potential of the aqueous component of pesticide droplets the rate can be considered to be constant for a given Delta T.

- Preferred Delta T conditions for spraying
- Marginal Delta T conditions for spraying
- Conditions are marginal for COARSE or greater spray quality and unsuitable for medium or finer spray quality
- Unsuitable Delta T conditions for spraying

Source: Adapted by Graeme Tepper (2012) originally sourced from Nufarm's Spraywise Decisions chart (2012)

10 tips for reducing spray drift

FOR MORE INFORMATION: SPRAY APPLICATION MANUAL FOR GRAIN GROWERS
grdc.com.au/resources-and-publications/grownotes/technical-manuals/spray-application-manual

1	Choose all products in the tank mix carefully, which includes the choice of active ingredient, the formulation type and the adjuvant used.
2	Understand how product uptake and translocation may impact coverage requirements for the target. Read the label and technical literature for guidance on spray quality, buffer (no-spray) zones and wind speed requirements.
3	Select the coarsest spray quality that will provide an acceptable level of control. Be prepared to increase application volumes when coarser spray qualities are used, or when the Delta T value approaches 10 to 12.
4	Always expect that surface temperature inversions will form as sunset approaches and that they are likely to persist overnight and beyond sunrise on many occasions. If the spray operator cannot determine the presence or absence of an inversion then spraying should not occur.
5	Use weather forecasting information to plan the application. Use observations in the paddock at the time of application. Access real-time data and forecasts from the spray inversion network Weather and Networked Data (WAND) that has been developed by the grains and cotton industries in partnership with Goanna Ag (wand.com.au).
6	Only start spraying after the sun has risen more than 20 degrees above the horizon and the wind speed has been above 4 to 5km/h for more than 20 to 30 minutes, with a clear direction that is away from adjacent sensitive areas.
7	Higher booms increase drift. Set the boom height to achieve double overlap of the spray patterns. With a 110 degree nozzle using 50cm nozzle spacing, the correct boom height is 50cm above the top of the stubble or crop canopy. Boom height and stability are critical. Use height control systems for wider booms or reduce the spraying speed to maintain boom stability/height. An increase in boom height from 50 to 70cm above the target can increase drift fourfold.
8	Avoid high spraying speeds, particularly when ground cover is minimal. Spraying speeds more than 16 to 18km/h with trailing rigs and more than 20 to 22km/h with self-propelled sprayers greatly increase losses due to effects at the nozzle and the aerodynamics of the machine.
9	Be prepared to leave unsprayed buffers when the label requires, or when the wind direction is towards sensitive areas. Always refer to the spray drift restraints on the product label.
10	Continually monitor the conditions at the site of application. Always measure and record the wind speed, wind direction, temperature and relative humidity at the start of spraying and at the end of every tank, according to the label requirements. Where wind direction is a concern move operations to another paddock. Always stop spraying if the weather conditions become unfavourable.

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1. Atmospheric stability

"Atmosphere stability is one of the most important factors in determining spray dispersion." – Miller et al., 2012

"Small changes in the stability condition can produce very large and quite rapid changes in the concentration of airborne plumes and the amount depositing to the surface."

"It has been found that in stable conditions, when vertical motion is suppressed, airborne pesticides don't disperse vertically but move horizontally at high concentrations near the ground. Whereas in unstable conditions, when vertical motion is enhanced, airborne pesticides tend to mix upward to weaker concentrations." – Miller et al., 2001

Twin concepts of stability

1 Static stability controls the buoyancy of air. Rising, unstable air is very important for weather formation. Air that will not rise is stable air correlated to air pollution. Inversions occur when the air is statically stable. As useful as static stability is, it neglects the effect of wind and wind shear, which are important drivers of drift.

2 Dynamic stability combines effects of static stability, wind and wind shear to provide knowledge of three-dimensional turbulence intensity that has critical influence on deposition and dispersion of drift. The combined effects of static stability and turbulence intensity need to be known before a surface temperature inversion can be identified as being hazardous or non-hazardous for spraying.

States of stability

States of stability control vertical motion in the atmosphere. A stable atmosphere resists vertical motion, while an unstable atmosphere assists it. When the atmosphere neither resists nor assists vertical motion it is said to have neutral stability.

Unstable conditions lift and mix pesticides into the air above to weak concentrations. The volume of drift entering the atmosphere may be difficult to detect when lifted rapidly away from the surface. The rapidity of lift and the vigour of mixing are largely determined by how unstable the atmosphere is.

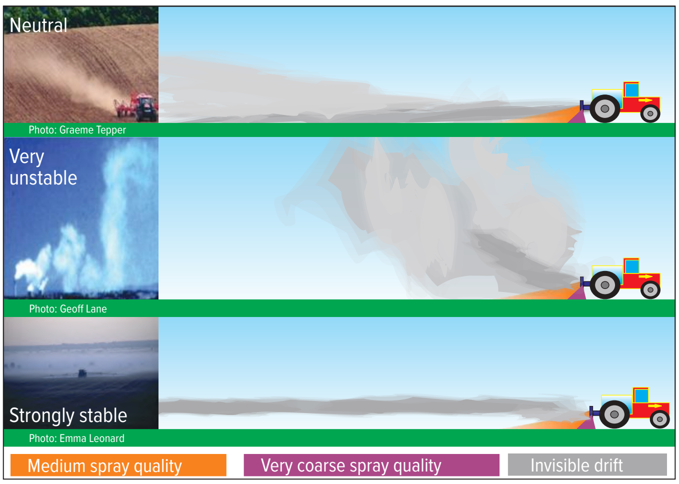
- **Weakly unstable** conditions are associated with fine-weather cumulus clouds and gentle thermals that lift spray drift away from the surface. Gentle turbulence causes spray drift to be slowly mixed and widely dispersed into the atmosphere.
- **Strongly unstable** conditions are typically associated with whirly winds, thunderstorms, tornadoes and widespread rapid lifting of spray drift away from the surface and rapid-widespread dispersion into the atmosphere. This condition, combined with strong winds and turbulence, is associated with dust storms.

Neutral conditions do not promote or restrict dispersion and are considered to be the ideal spray conditions. In neutral conditions, drifting pesticides fan out in a cone-like pattern that partly intercept the surface – thereby promoting droplet deposition. However, some pesticides rise away from the surface due to the vertical expansion of the cone pattern.

Stable conditions are synonymous with surface temperature inversions. The term inversion is commonly used to describe all variations of stable conditions. Recent research reveals that the impacts inversions have on spray drift vary significantly depending on whether the atmosphere is weakly or strongly stable.

- **Weakly stable** conditions are moderately to strongly turbulent. These intensities of turbulence do not support long-distance concentrated drift; they support dispersion. The level of turbulence in the weakly stable regime is comparable to the turbulence typically observed in near-neutral conditions that are recommended under current guidelines as suitable for spraying.
- **Strongly stable** conditions are only weakly turbulent. Weak turbulence is not conducive to dispersion. Laminar winds with weak turbulence are capable of transporting drift at high concentrations for long distances across the surface. On a typical summer's night laminar winds could theoretically carry drift more than 80 kilometres across the surface without vertically dispersing. Laminar winds are known to be associated with long distance and widespread damaging drift.

Figure 3: Three common states of atmospheric stability and their relationship to spray application and drifting sprays.



Neutral conditions favour drifting plume deposition to the near surface but some percentage will also be transferred to the wider atmosphere.
Strongly unstable conditions promote vertical dispersion and widespread dispersion of plumes into the atmosphere.
Strongly stable conditions (hazardous inversions) cause high concentration of drifting plumes near the surface in contained layers.

Smoke from home fires trapped by strongly stable inversion conditions and transported by strong drainage winds. Note the smoke fumigating to the surface and multiple smoke sources merging into one concentrated plume. The motion and transport of smoke here mimics that of pesticides drifting in similar hazardous inversions. Photo: Pete Nicolaison

2. Wind

Horizontal and vertical winds transport drifting sprays away from the site of application.

Turbulent air flow will disperse drift if sufficiently strong. Drift will not disperse if the air flow is only weakly turbulent.

Vertical winds are generated by convective thermals. Thermal winds during the middle of the day cause large-scale three-dimensional motions in the atmosphere, which mix surface heat, moisture and aerosols to thousands of metres into the atmosphere.

Synoptic winds are those dictated by weather map patterns.

Local winds are generated when synoptic winds are decoupled by inversions. They are most prominent when hazardous inversions exist.

Cool air drainage winds are the best known locally generated winds. They flow off slopes like sheets of water. Differential heating across landscapes and surface slope are the major determinants of their generation, direction and speed. Atmospheric stability has a major influence on local wind flow generation and turbulence.

Wind and three-dimensional motions determine:

- the intensity of turbulence;
- the distance travelled and the destination of drift;
- the concentration of what's drifting;
- the distribution of pesticides in the atmosphere; and
- the distance to deposition and the area affected.

Spray guidelines

Bureau of Meteorology forecasts and observations refer to horizontal wind speed and direction averaged over 10 minutes at a height of 10m above the surface.

The below guidelines refer to winds at a height of 2m above the surface.

- Spray only when wind direction is away from sensitive areas (use of buffers may vary this requirement).
- During the day, aim to spray when wind speed is more than 5km/h and up to 15km/h.
- Do not spray if wind is less than 5km/h or at any wind speed where constancy in direction is not assured.
- Be very wary of spraying at night when winds are equal to or less than 11km/h. Such light winds often accompany hazardous inversions.

High wind speed (above 15km/h) can lead to high volumes of downwind drift, with highest concentrations close to the target and lowest concentrations further downwind. High wind speeds are the primary cause of loss and waste of product from the target site.

Winds between about 7km/h and 18km/h, having consistent direction, are generally best for spraying as they promote optimal droplet deposition and least drift potential.

Low wind speed (less than 5km/h) tends to be associated with unpredictable wind direction and very little turbulence. Also refer to page 23 – Precautions for night spraying.

Turbulence

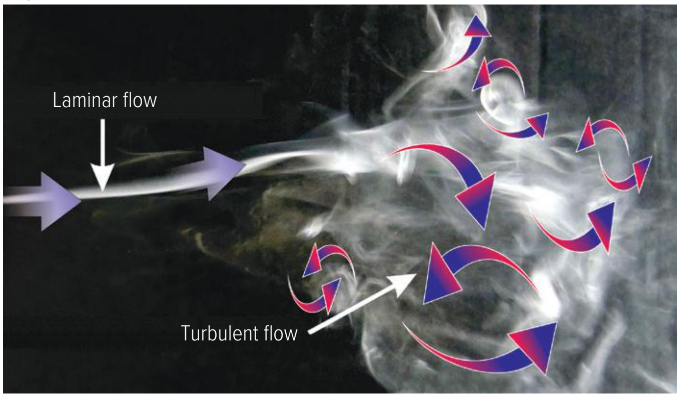
Turbulence is the driver of dispersion. When active it efficiently mixes surface air to higher levels and decreases the concentration of suspended material.

Weak turbulence leads to the concentration of airborne material near the surface. It causes drift to hang over the surface and move horizontally for long distances at high concentrations. Weak turbulence is a feature of hazardous inversions.

Mechanical, thermal and wake turbulence act on drifting pesticides.

- Mechanical turbulence is generated by surface friction and obstacles disturbing the air flow.
- Thermal turbulence is generated by convective circulations driven by solar surface heating.
- Wake turbulence is generated by wind flow interactions with the machine and can lift sprayed pesticides above the machine; thereby increasing the volume of drift.

Figure 4: Turbulence.



A smoke plume initially illustrates laminar flow before breaking up into turbulent flow. Note the consistent high concentration within the laminar flow and the turbulent eddies, and mixing within the turbulent flow.

Source: Graeme Tepper

To the left of this image smoke rises turbulently into the surface temperature inversion layer before being caught up in laminar-flowing winds within the inversion. Note that the smoke particles hang near the surface and travel several kilometres before setting into a low-lying area. Photo: Bill Campbell

Intense turbulence leads to rapid dispersion of airborne pesticides both horizontally and vertically. It takes larger particles down to the surface and lifts smaller particles high into the atmosphere where they will be dispersed to diluted concentrations, reducing, but not eliminating, the risk of off-target damage.

It is important to note that as turbulence intensity increases it not only acts to rapidly disperse pesticides, but also acts to keep airborne pesticides in suspension in the atmosphere for long periods – potentially months.

Synoptic winds

Synoptic winds flow over several hundreds or thousands of kilometres, dependent on pressure gradients of the weather pattern. They are the winds usually referred to in general weather forecasts (sea breezes being the exception for coastal regions) and are measured at a height of 10m above the ground.

Local winds

Local winds frequently flow completely independently of the synoptic flow, with different direction and speed.

Onset and cessation of local winds can be rapid. Therefore, local winds need to be carefully monitored to ensure operating practices remain tailored to prevent pesticides drifting towards sensitive areas.

Local winds are most pronounced after sunset and decline in influence at sunrise.

Local wind flows are caused by:

- on-slope cooling (drainage winds – Figure 6);
- on-slope heating (anabatic winds – Figure 7);
- terrain blocking (blocked winds – Figure 8);
- differential heating (sea and land breezes – Figures 9 and 10);
- cool air falling downslope (downslope winds – Figure 11);
- excessive heating (thermals – Figure 12); and
- density currents (far-inland sea breezes).

Measuring local winds

Frequent observations are required to track local winds. Instruments are best, but ribbons attached to the end of the boom or on fence lines, smoke pots and smoking devices fitted to the tractor's exhaust can all help indicate wind strength and direction. Handheld wind meters should be held at a height of 2m.

Wind shear

Wind shear exists when wind direction and speed change with altitude. Wind shear leads to airborne pesticides being transported in directions other than that indicated by the surface direction.

Applicators should be wary of wind shear effects from sunset and up to about an hour-and-a-half after sunrise, when a surface temperature inversion is progressively eroding.

To anticipate wind shear, applicators need to compare the overriding synoptic wind flow to the paddock surface winds.

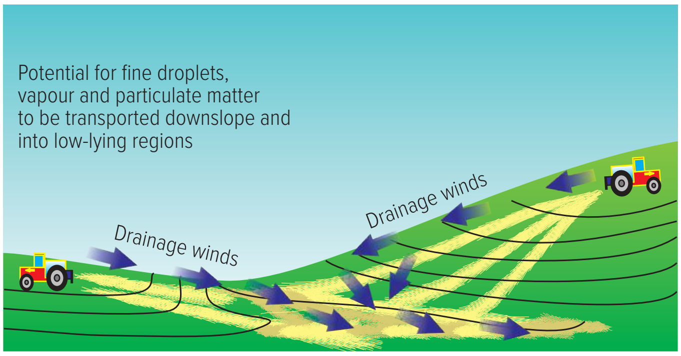
For example, if the general wind flow indicates westerly winds but the actual surface winds are easterly, then there is significant wind shear. If overnight winds have a similar direction to the general wind flow, wind shear will be minimal (Figure 13).

The wind shear most relevant to spray applicators is likely to occur when surface temperature inversions and drainage winds dominate local surface wind flow, while winds above the surface are dominated by the synoptic flow.

Figure 5: Wind shear.

The smoke plume rises because the air is being heated by the fire and becomes buoyant. Smoke-laden air rises into a surface temperature inversion, where it is partially trapped. At different altitudes, wind shear transports smoke particles in varying directions. Source: Graeme Tepper

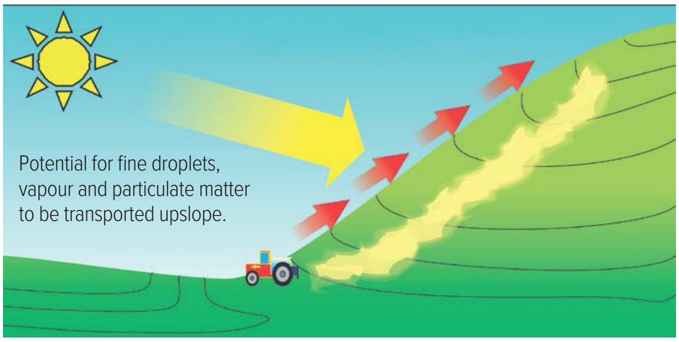
Figure 6: Drainage winds – overnight.



During a surface temperature inversion, drainage winds often occur, with air flowing to the lowest point in the catchment. Drainage flow can be deflected by obstacles in a similar fashion to water flowing downhill. These winds can develop over the slightest of slopes. Drainage winds can carry concentrated airborne pesticides long distances, which can result in widespread pesticide damage many kilometres away from the application site.

Source: Graeme Tepper

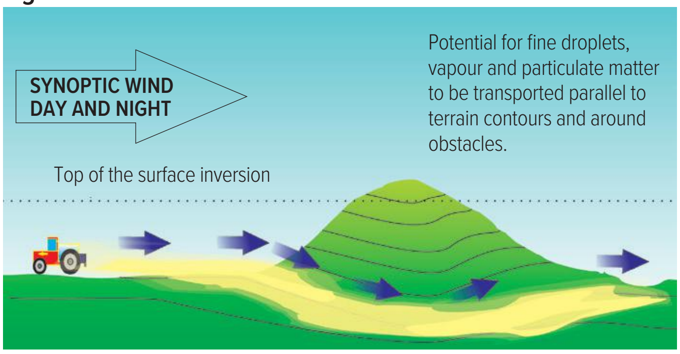
Figure 7: Anabatic winds (upslope).



Anabatic winds are warm winds that flow up and parallel to steep slopes or mountain sides in response to heating of the surface and of the air in contact with the surface. Anabatic winds are most pronounced in the early morning and sometimes in the evening when the sun is low in the sky. Pesticides can be carried upward through crops positioned on steep slopes when anabatic winds exist and spray drift occurs.

Source: Graeme Tepper

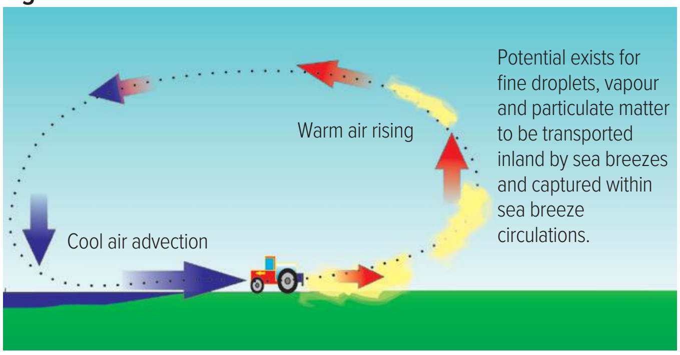
Figure 8: Blocked winds and contour wind flow.



Blocked winds occur upwind of obstacles when cool dense air cannot flow over them (usually a temperature inversion exists). The winds tend to be very localised due to vegetation (for example, tree belts), levy banks and buildings, or they can be more wide-reaching due to hills and major changes in topography. They tend to flow along contours and can carry concentrated airborne pesticides long distances, which can result in long-distance drift and widespread damage.

Source: Graeme Tepper

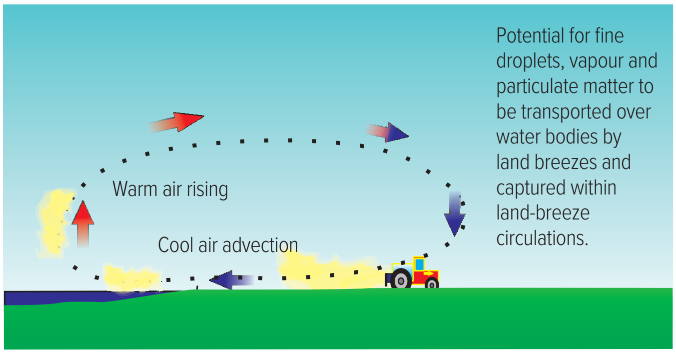
Figure 9: Sea breeze circulation.



Sea breezes, occurring most often from mid-morning to late afternoon, can override or reinforce synoptic wind flow. Occasionally, sea breezes generate a surge of cold air that can penetrate well inland (for example, Renmark, South Australia, and Kalgoorlie, Western Australia). These inland incursions may affect applications by inducing rapid changes in wind speed and wind direction. They can shift large volumes of pesticides long distances.

Source: Graeme Tepper

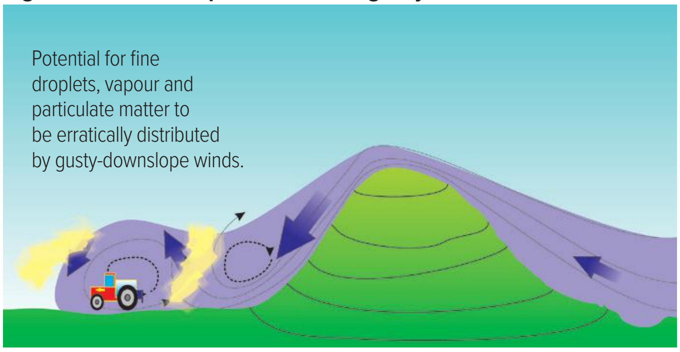
Figure 10: Land breeze circulation.



Land breezes typically occur at night when warmer air over the water surface rises and cooler air from the land is drawn into this space. Land breezes have the potential to carry concentrated airborne pesticides to water surfaces. In combination with sea breezes, they can recirculate airborne pesticides between land and water surfaces.

Source: Graeme Tepper

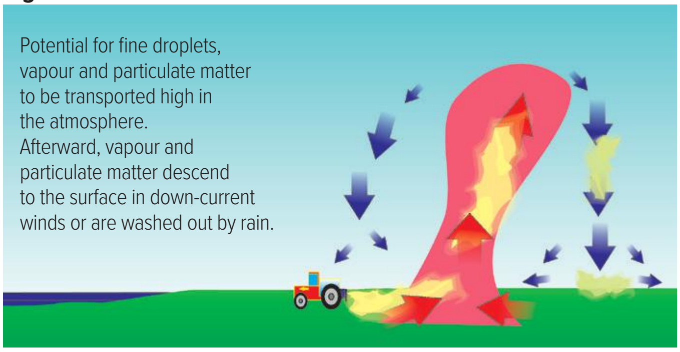
Figure 11: Downslope winds and 'gusty' rotors.



Downslope winds present as intermittent, strong and gusty winds on the downwind slopes of rather steep terrain. They develop when cool air banks up behind an obstacle and spills over before running downslope, similar to water periodically running over the top of a dam. Downstream from the obstacle, turbulent rotors may generate rapid shifts in wind direction and speed, to several kilometres from the foothills.

Source: Graeme Tepper

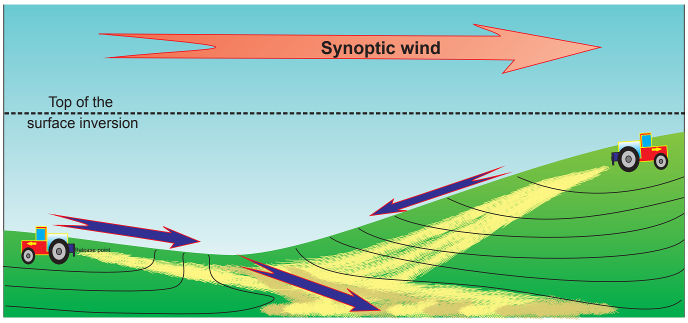
Figure 12: Thermal winds.



Thermals are drafts of warm air rising from the ground. These air currents begin to form as the sun rises. They intensify as the surface heats up during the day and weaken as it cools during late afternoon and evening. They are extinguished by sunset, unless the surface retains enough heat to remain hotter than the air above. The upward speed of thermals depends on surface heating and the temperature of the overlying atmosphere. High surface temperatures with very cool air above lead to vigorous thermals capable of lifting airborne pesticides high into the atmosphere.

Source: Graeme Tepper

Figure 13: Cool-air drainage winds flow independent of the synoptic flow.



The variation between the direction of synoptic winds flowing above the surface and the drainage winds illustrates the difference between a sheared and non-sheared environment.

Source: Graeme Tepper

Diurnal wind variation

In rural settings, it is often noticeable that wind speed peaks soon after midday, decreases toward evening and increases again after sunrise. These diurnal oscillations of wind speed are caused by diurnal oscillations of atmospheric stability.

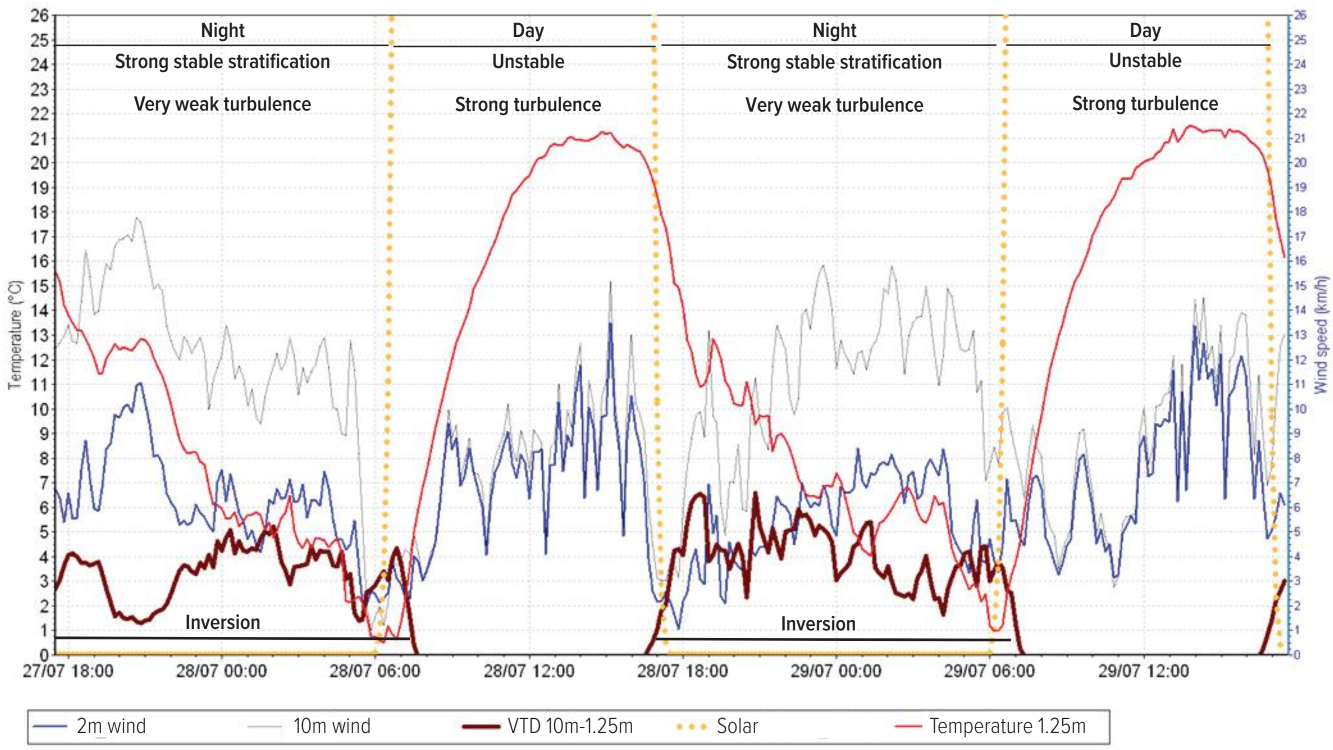
In general, when the atmosphere is warmest and most unstable winds are strongest because turbulent mixing brings higher level winds down to the surface. Again, in general, during the afternoon winds decrease while the atmosphere trends away from unstable toward stable and mixing diminishes.

When the atmosphere becomes strongly stable, the upper level winds completely decouple from the surface and local winds begin to develop. Local wind direction and speed is dictated by land slope and orientation and often flow in different directions to the synoptic wind.

In strongly stable conditions cool-air drainage winds are common across agricultural lands, so are cool winds flowing parallel to terrain contours, gusty gully winds and downslope winds just downwind of steep terrain.

In the morning as the sun rises and the atmosphere trends from stable to unstable, higher level winds recouple to the surface, destroying local wind flows.

Figure 14: An example of diurnal variations of winds at 10m and 2m, temperature (bright red line) and inversion occurrence (dark red line indicates the vertical temperature difference between 10m and 1m) at a site near Wee Waa, NSW.



Vertical axis indicates km/h and degrees. The horizontal axis indicates time of day. Strong turbulent mixing is indicated by 10m and 2m winds being similar. Weak turbulence is indicated by large separation between the 10m and 2m wind speeds, or winds lighter than about 5km/h being much the same.

Source: Graeme Tepper

3. Temperature

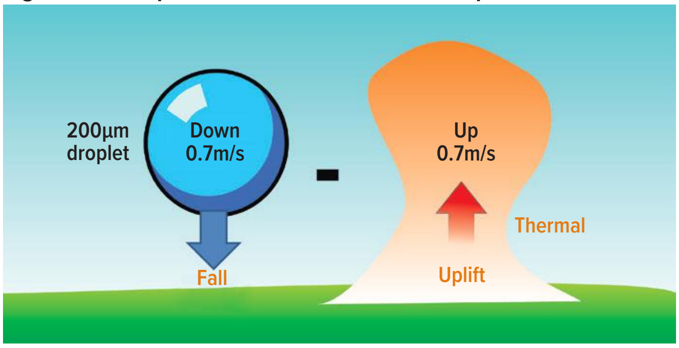
The temperature of the air into which pesticides are sprayed and the temperature of the surfaces the pesticides settle onto impact droplet survival, efficacy and volatilisation.

Temperature and pesticide application

As temperature increases:

- droplets evaporate faster because warm air can hold more moisture than cool air;
- turbulence intensity generally increases because the atmosphere becomes more unstable;
- volatile pesticides on soil and plant surfaces vaporise faster because vapour pressure increases as temperature increases; and
- the potential for thermals to lift airborne pesticides into the atmosphere increases because increasing the temperature ordinarily increases the height to which thermals rise.

Figure 15: Droplet fall rate versus thermal uplift.



Comparison of the typical fall rate of a 200µm droplet and speed of a typical thermal updraft on a warm day illustrating the power of thermals to lift droplets that would normally be considered 'undriftable droplets'.

Source: Graeme Tepper

Surface to air temperature variations

Surface temperature variations compared with the air just above the surface can be extreme. With strong sunlight, the surface temperature of bare ground can be more than 20°C higher than the air temperature 1.25m above the ground, the standard height of temperature measurement by the Bureau of Meteorology.

Heat loss to clear night skies can lead to surface temperature being several degrees cooler than minimum temperatures quoted by the Bureau of Meteorology.

Besides incident solar radiation, the rate of cooling and heating at the surface is dictated by the nature of surface vegetation, soil type, moisture and wind speed.

A common guideline is to spray only when air temperature is less than 30°C. However, soil temperature, especially in summer with sparse vegetation, can be considerably higher than the air.

The total effects of applying herbicides to sparse vegetation over hot soils may not yet be fully determined, but from a meteorological point of view the concerns include:

- the possibility of the rapid evaporation of droplets approaching the surface and becoming highly drift-prone, especially smaller droplets that approach the surface slowly; and
- larger droplets, which would normally be expected to reach the surface, being captured and lifted by strong thermals to become spray drift (Figure 15).

One solution is to use the largest droplets possible while maintaining efficacy and to operate the machine in a configuration and at a speed to minimise the production of drift-prone droplets.

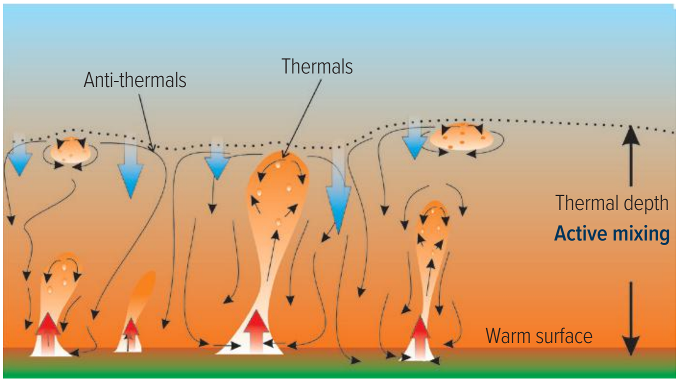
Diurnal temperature variations

The experience of walking barefoot on bare soil or sand on a clear hot day before jumping to green grass or shade informs us of just how different air and surface temperature can be. At night the differences are not so noticeable but bare surfaces are generally significantly colder than air temperature. These differences (even when small) have critical impact on the stability of the atmosphere:

- **during the day** – they lead to instability in the atmosphere with vigorous vertical mixing into which airborne pesticides dilute (Figure 16); and
- **at night** – they lead to stability of the atmosphere and inversion occurrence. When the atmosphere becomes strongly stable only weak mixing occurs close to the surface. In these conditions airborne pesticides tend to be contained at high concentration near the surface (Figure 17).

The concentrated layer of pesticide can drift a long way; distances of up to 40km have been recorded. Movement of the pesticide is likely to be dictated by local winds rather than the synoptic wind.

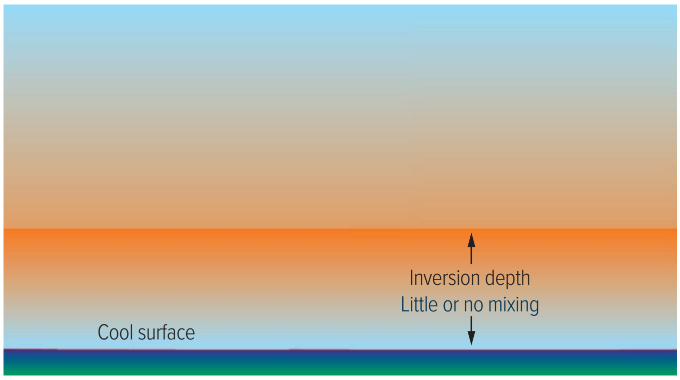
Figure 16: With surface heating, a daytime mixed layer is developed by thermals and 'anti-thermals'.



The height to which thermal mixing occurs is dependent on the vigour of thermals and varies from just a few metres in the early morning to up to several thousand metres by the middle of a hot afternoon before decreasing to a few hundred metres by late afternoon. Thermal mixing is usually extinguished overland at night due to the onset of stable conditions (inversions).

Source: Graeme Tepper

Figure 17: With surface cooling at night an unmixed layer develops, equivalent to the inversion depth.



The depth of the surface temperature inversion increases from just a few metres at around the time of sunset to several hundreds metres just before sunrise.

Source: Graeme Tepper

Volatilisation

Volatilisation occurs when pesticide surface residues change from a solid or liquid to a gas (vapour).

Vapours can be released at the time of application but the primary source of vapours is from soil and plant surfaces for hours or days after application. Vapour integration with other atmospheric particles can extend the period they impact receptors.

Higher temperature of soils and plants increases volatilisation rates and promotes the transfer of vapours into the atmosphere. Volatilisation may represent a major dissipation pathway for pesticides applied to soil or crops.

At night in cooler conditions when the atmosphere is very stable, vapours rates of release may be less than during the day but concentrations moving across the surface may be higher.

Pesticides able to volatilise over days will encounter diurnally varying temperatures and humidity and multiple states of stability, leading to dispersion by day and concentration by night, suggesting that application of volatile formulations need to be undertaken with acute awareness of the variety of stability conditions over some hours or days following an application.

Paddocks having a high proportion of bare ground or crops with open rows are likely to exhibit high surface soil temperatures during the day and cool surfaces during the night. These diurnal variations are likely to promote strong intermittent and variable winds with strong convective mixing during the day, leading to low concentrations of vapours being detected during the day. During the night such surfaces will promote the establishment of hazardous inversions and high concentrations of vapours in laminar wind flows.

4. Evaporation

When it is hot we naturally link temperature to evaporation. When it is cool we do not expect too much evaporation. However, the rate at which spray droplets evaporate is mainly determined by the amount of water vapour the air can absorb, the droplet volume compared with its exposed surface, the chemical formulation and the nature of the airflow over the droplet.

Relative humidity

Relative humidity (RH) is the ratio of the actual amount of water vapour in the air to the amount it can hold when saturated. The air's capacity to hold water vapour increases as air temperature rises. At 30°C, the capacity is more than three times that at 10°C; consequently, while the amount of water vapour in the air may be static, the relative humidity decreases as temperature increases (Figure 18).

Delta T

A better indicator of the rate at which pesticide droplets evaporate is Delta T. Delta T is the difference between the wet and dry bulb temperatures. It combines the effects of temperature and relative humidity (Figure 19).

For example, the evaporation potential is about the same for:

- 20°C and 38 per cent RH and a Delta T of 8; and
- 30°C and 50 per cent RH and a Delta T of 8.

The amount of water vapour in the air usually only changes gradually over days, while temperature changes at a comparatively rapid rate. This leads to higher relative humidity values and lower Delta T values overnight compared to during the day.

Relevance for spraying

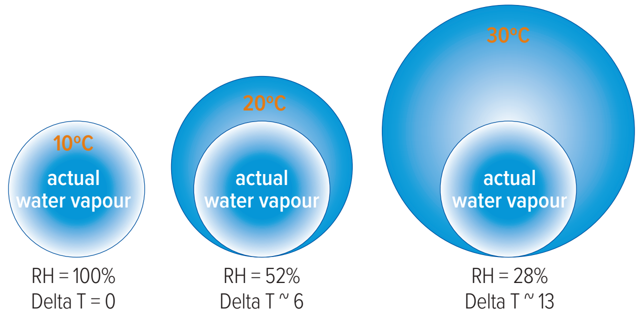
Rapid evaporation of the aqueous component of large droplets can lead to unexpectedly high volumes of droplet and particle drift, much higher than spray quality might indicate.

As spray droplets reduce to less than 150µm diameter they become highly susceptible to drift and can be transported over long distances by air currents before being deposited (Unsworth et al, 1999).

Partial evaporation of the aqueous component of droplets before reaching the target leads to ever-decreasing droplet size and higher concentrated droplets, slower fall rates and high potential for drift.

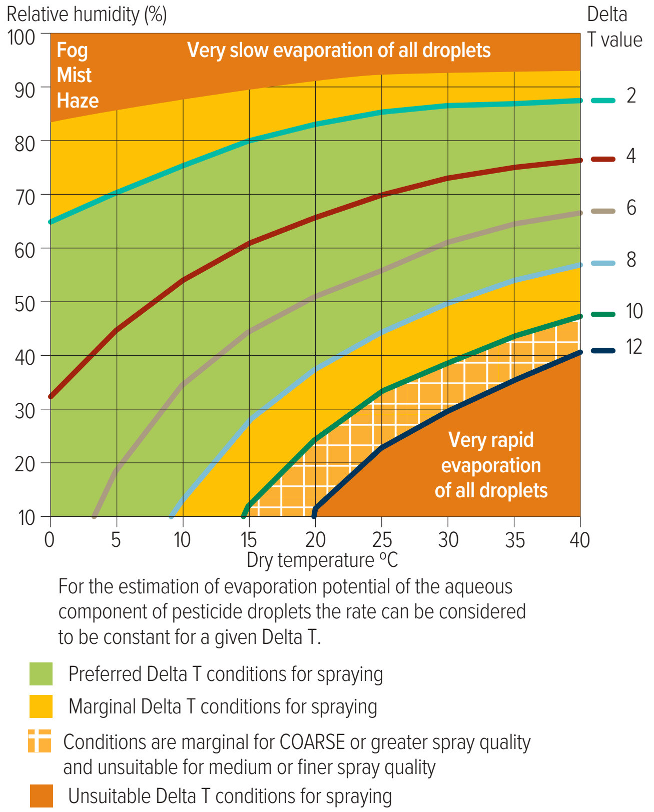
Total evaporation of the aqueous component of droplets before reaching the target leads to airborne gaseous and particulate residues of the active component, plus impurities and additives floating in the atmosphere. The initial residues of evaporation are highly concentrated forms of the active pesticide. If not adequately dispersed by turbulence, they can lead to damaging drift for kilometres downwind.

Figure 18: A depiction of one air parcel undergoing a temperature change while the amount of moisture remains the same.



Source: Graeme Tepper

Figure 19: The relationship of Delta T to relative humidity and temperature. A common spray guideline is to spray when Delta T is between 2 and 10, with caution below 2 or above 10.



Source: Adapted by Graeme Tepper (2012) originally sourced from Nufarm's Spraywise Decisions chart (2012)

No evaporation of the aqueous component of small droplets already in suspension can lead to unacceptably long life and long-distance drift.

Very small droplets, vapour and particle residues that remain airborne for a considerable time are cause for concern beyond direct spray drift issues. These residues are finally brought back to the surface in precipitation or incorporated in fog where they may re-emerge into the atmosphere after fog dissipation. The primary pathways for the return to the surface of residues are:

- interception/impaction (capture by obstacles or raised terrain);
- with rain;
- fog (droplet settling); and
- air currents (downward flow).

5. Hazardous surface inversions

Pesticide applications during hazardous surface temperature inversions can lead to spray drift, causing severe damage up to several kilometres off target. Current regulations prohibit spraying of agricultural chemicals when hazardous temperature inversions exist.

"When application occurs in an area not covered by recognised inversion monitoring weather stations, all the surface temperature inversion conditions are regarded as hazardous."

– Australian Pesticides and Veterinary Medicines Authority (APVMA)

Key points

- Spray applied at dawn, dusk and during the night is likely to be affected by an inversion.
- During hazardous inversions, air movement is much less turbulent than during the day.
- Weak turbulence leads to the accumulation of drift close to the surface.
- Airborne droplets can remain concentrated in the inversion layer for long periods of time.
- The direction and distance airborne droplets will move within an inversion is unpredictable and will vary depending on the surrounding landscape.
- Spray applicators should continuously monitor for inversions overnight, because they occur at any time between dusk and mid-morning.
- Spraying into hazardous inversions may lead to widespread damaging drift.

Under a surface temperature inversion, air can separate into strongly stable layers (laminates) that can concentrate and transport airborne pesticides away from the target.

Photo: Bill Gordon

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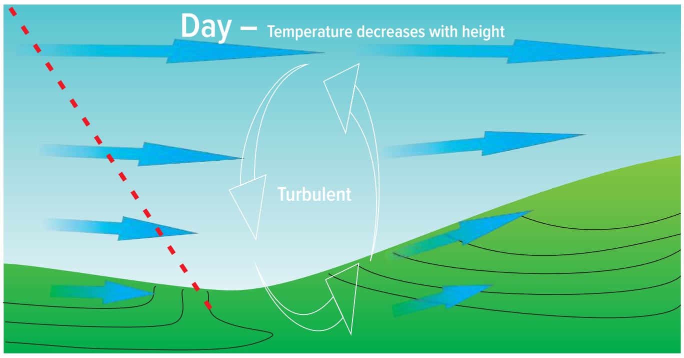
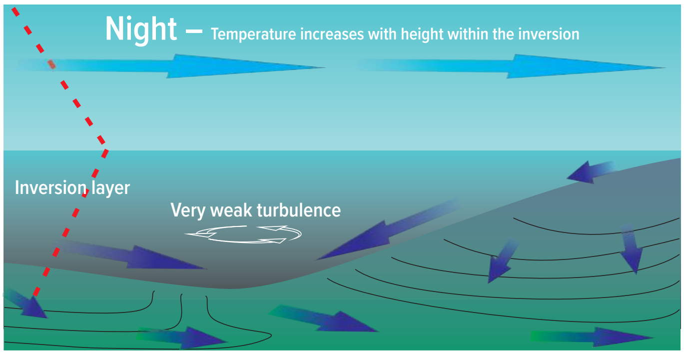
During a hazardous inversion, very weak turbulence supports the transport of drift over long distances and widespread deposition at high concentrations. When a hazardous inversion has established, it acts like a barrier, isolating the inversion layer from the normal weather situation, especially the normal synoptic wind speed and direction. Cool-air drainage winds often flow off slopes – even the slightest of slopes – when the inversion barrier exists.

Figure 20: Typical daytime compared to night-time conditions over farmlands.



During the day: Temperature decreases with elevation (red dashed line). Winds flow across the landscape (light blue arrows). Turbulence is active to several thousand metres above the surface.



During the night: Temperature increases within inversions. Surface winds flow toward low-lying regions. Turbulence is weak, intermittent and confined to narrow layers near the surface when hazardous inversions exist.

Occurrence of surface inversions

Surface inversions exist most nights from an hour before sunset and up to an hour or so after sunrise. In the presence of inversions, wind speeds can be surprisingly strong and cloud cover can be extensive. Wind speeds to 20km/h are not uncommon. Average winds are usually between 2 and 15km/h at 2 metres. The most hazardous inversions occur when wind speeds are from 2 to 11km/h at 2 metres.

Only heavily overcast skies and stronger winds preclude the formation of inversions. Transient clouds cause variations in temperature and thereby impact inversion conditions.

Surface inversions are primarily generated by surface radiative cooling. However, they can be generated by cool air advection with sea breezes and drainage winds.

Myth busting

There is a common misconception that surface inversions only form when wind speeds are less than 3km/h and skies are clear. Such conditions are simply the most ideal conditions for surface inversions to form.

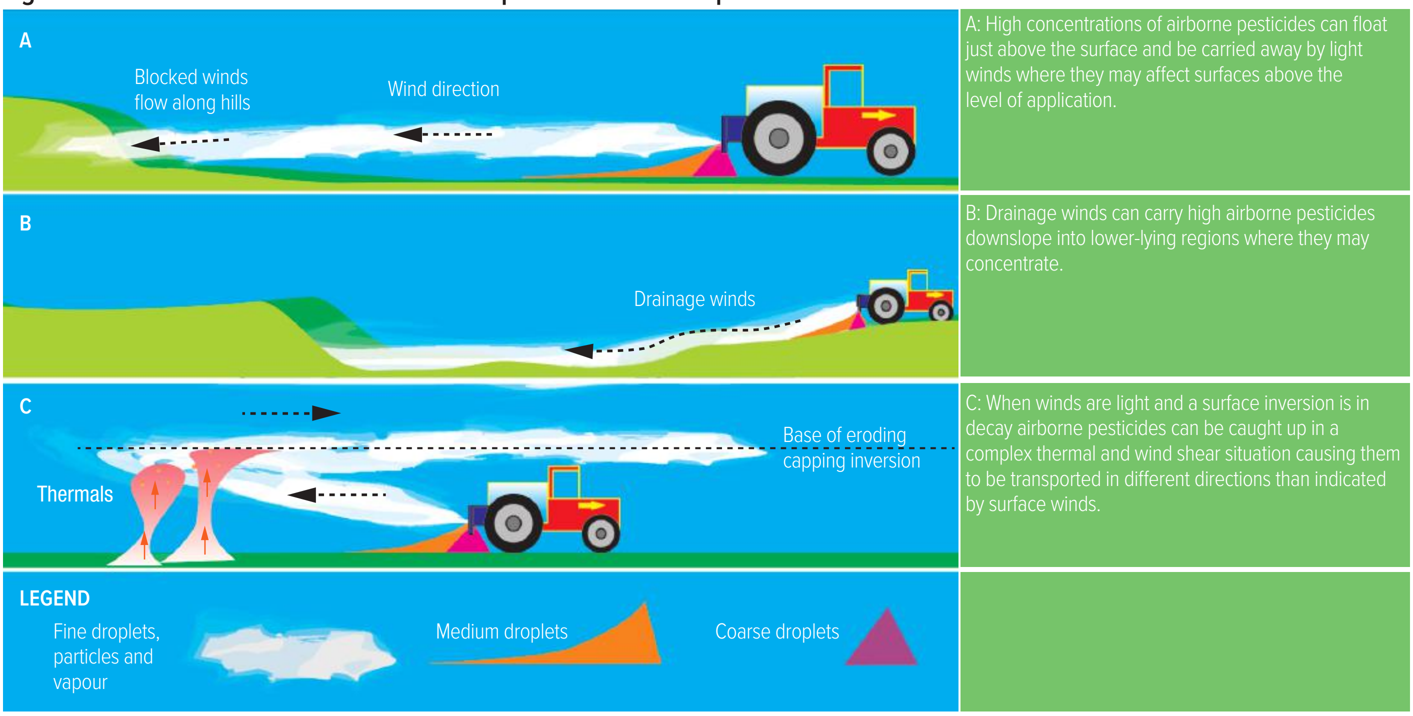
Australian research shows that when inversions exist that 25 per cent of winds are 3km/h or less, 67 per cent are between 4 to 10km/h and 8 per cent are between 8 and 20km/h when measured at 2m above the surface and skies can be overcast.

Wind effects

In the cool and dense air of hazardous inversions, drift can be captured in laminar winds that glide smoothly down slopes, deviate around obstacles, flow parallel to contours and generally flow towards low-lying areas where they converge; all the while transporting airborne material such as spray drift.

Winds should be measured at a height of 2m for spray records, as per Australian Pesticides and Veterinary Medicines Authority (APVMA) advice.

Figure 21: Possible movement of airborne droplets in surface temperature inversion conditions.



Source: Graeme Tepper

Figure 22: Idealised air flow during the day typically increases in speed with height and flows up and over raised terrain, with stronger winds at hilltop (left). When a surface temperature inversion exists, surface winds decouple from the surface and flow over the inversion, with winds accelerating (low-level jet) over the top of the inversion. Within the inversion, winds are typically light and often drain down slope, regardless of the overlying wind direction (right).

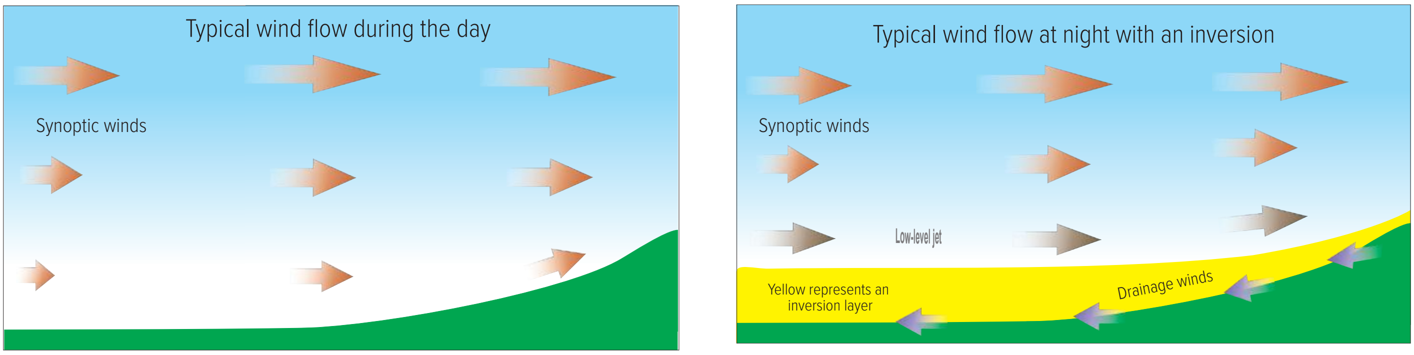
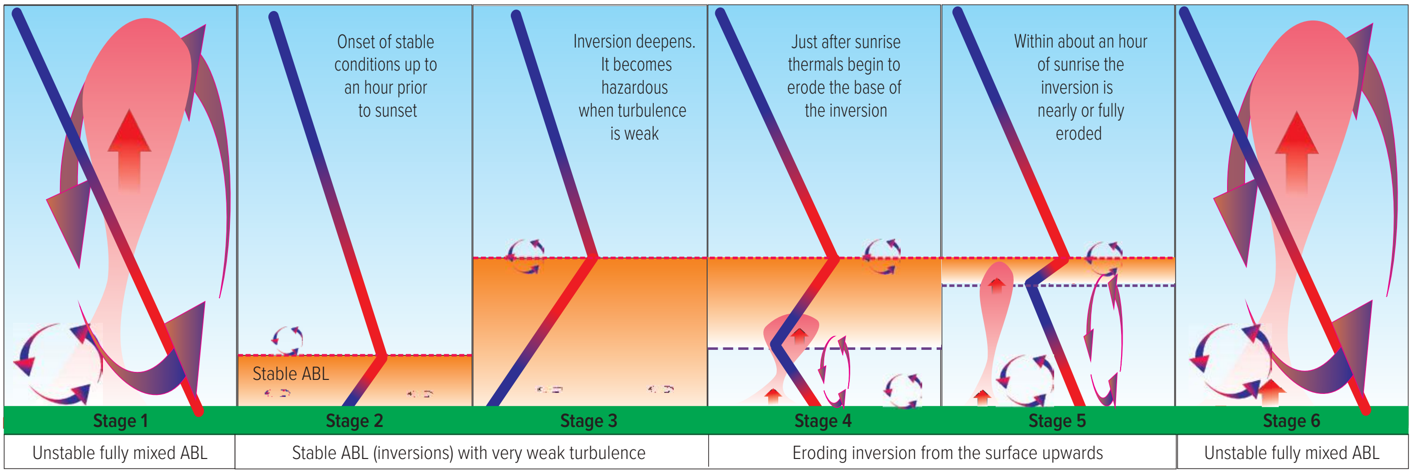


Figure 23: An idealised development and decay of surface temperature inversion with no wind and clear skies. The vertical temperature profile is depicted by the red/blue line.



Note: Figure 23 depicts an idealised inversion lifecycle. Exceptions occur when transient cloud and fluctuations of wind speed vary the surface cooling rate. For example, inversions may begin or cease anytime in the night, especially if the synoptic winds are increasing or decreasing as cold fronts, or troughs approach or leave an area. ABL = atmospheric boundary layer.

Figure 24: Pesticide particles can accumulate in the atmosphere for several days before being deposited on the surface.

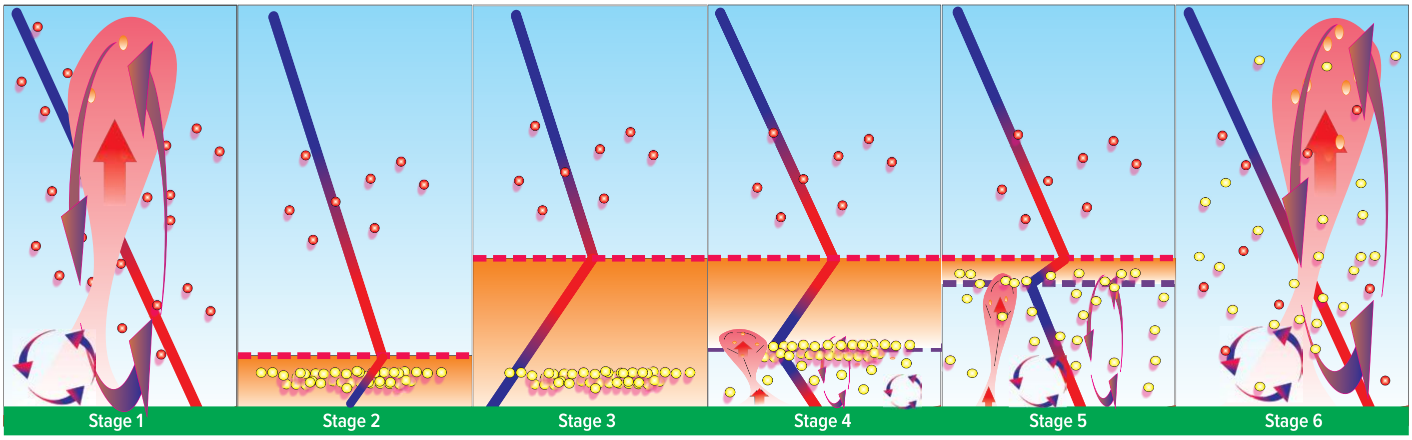


Figure 24 depicts a summer-time fine weather situation where thermals have lofted particles into suspension well above the surface. Spraying at night when an inversion exists causes particles to be suspended near the surface. The period of transition between the night-time inversion and the next day's thermal activity can herald the mixing of both suspensions, after which they may fumigate to the surface at sufficient concentrations to cause adverse effects.}

Source: Graeme Tepper

Within hazardous inversions wind speeds, when measured at 2m, generally vary from 2km/h to 11km/h. Speeds in excess of 11km/h can occur, but are generally short-lived.

- Do not spray if wind is calm or less than 5km/h, or at any wind speed where consistency in direction is not assured.

Idealised air flow for day and night is shown in Figure 22 on page 20.

Inversion lifecyle

The development and structure of an inversion is not straightforward (Figure 22). The timing and structure can vary. Therefore, it is advisable to constantly monitor for inversions from an hour before dusk to an hour or so after sunrise.

Variations of inversion life cycle occur in response to:

- the cooling of local terrain – shadowed landforms are first to experience inversions;
- clouds transiting across paddocks, which can intermittently weaken surface cooling; and
- wind speed variations, as winds may increase or decrease during the night.

On most nights, at least a weak surface temperature inversion will form even under overcast skies, unless winds exceed about 15km/h measured at 2m. Note that inversions have been detected with much stronger winds.

Typically, inversions weaken and rise off the surface shortly after sunrise in response to the sun warming the earth. Warming generates thermals that erode the inversion (Figures 23 and 24), while the higher levels of the inversion remain intact as a 'capping inversion' until the thermals and/or turbulence completely destroy the inversion.

Accumulation of pesticide residues in the atmosphere

If conditions are considered appropriate for spraying, the likelihood is that many applicators will be working within a region. Consequently, spray droplets from multiple sources could be carried into the atmosphere (Figure 24). The result is occasional excessive overloading of pesticide residues in the environment. This can be the cumulative effect of the suspension of pesticides from both day and night spraying events over a few days. This situation is especially pertinent to sustained periods of summer spraying when thermals are strong and inversions frequent.

Studies in pollution transport support the theory that pesticide residues could accumulate in the overhead air before being brought back to the surface.

Recognising a surface temperature inversion

Inversions should be expected on most nights. They most frequently exist from dusk to about an hour after sunrise, albeit with varying intensity. However, BEWARE: inversions can form many hours after sunset and cease well before sunrise, or they may occur only fleetingly overnight.

At what time inversions occur is highly dependent on wind speed, transient cloud and turbulence. The only reliable method of tracking inversions is to accurately and constantly measure the vertical temperature difference (VTD) with height.

Inversion wind

It is remarkable how strong wind speeds can be when inversions exist. Australian studies over agricultural regions indicate that when measured at a 2m height, average wind speeds are commonly up to 11km/h.

Many spray equipment operators will be surprised to learn that it is not unusual for winds to exceed 15km/h during inversion onset and cessation.

It is also remarkable that winds are rarely calm when inversions exist. The rarity of calm can be attributed to inversion being prerequisites for local wind development. Local winds over broadacre land with gentle slopes are often between 2 and 15km/h.

Inversion occurrence and wind speed examples

Figure 25 on page 22 presents an example of three inversion events recorded from 8–11 November 2019 near Dalby, Queensland. Similar winds are often observed to occur across Australian agricultural regions while inversions exist.

Key features of these three examples:

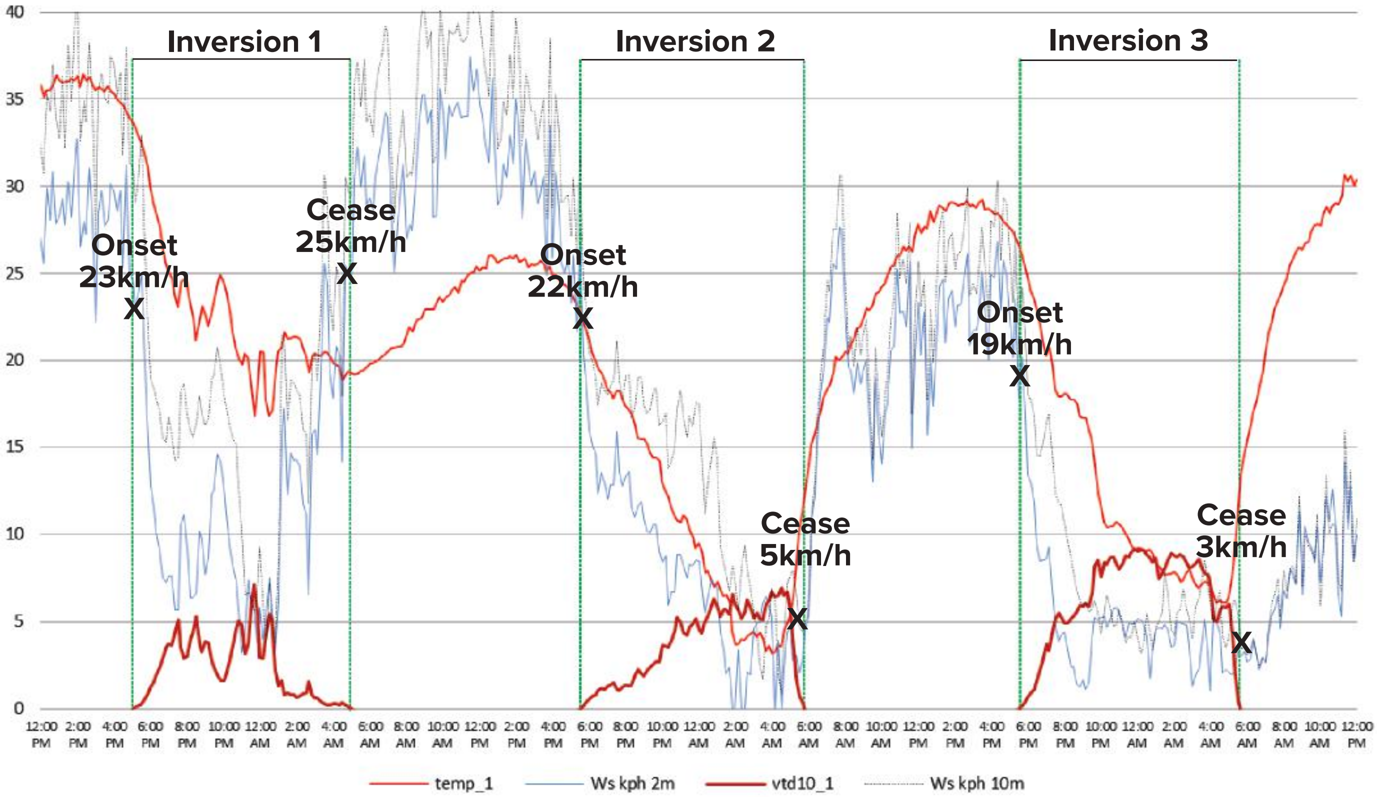
- Winds are rarely calm when inversions exist.
- Wind speeds are higher during the day than at night.
- The air is well mixed by strong winds during the day.
- Inversions occurred at least half an hour before sunset in winds greater than 15km/h, at 2m (sunset 6.18pm).
- Inversions ceased about an hour after sunrise (sunrise 4.59am).
- Inversion onset was signalled by significant wind speed decrease toward evening.
- Each inversions event is unique – this is typical for most regions.
- While these examples show peak vertical temperature difference with height (VTD) near midnight and 4am, other examples show peak VTD to occur an hour or so after sunset. Peak VTD is difficult to forecast.

Visual and other clues

Visual and other indicators may only become apparent hours after the onset of an inversion, or may not show at all. Visual and other indicators are last-resort tools for inversion detection. They should not be relied on for critical decisions. Only relying on clues is simply guesswork. Some indicators are:

- wind speed reduces rapidly during the afternoon in fair weather conditions;
- mist, fog, dew or frost exist;
- smoke or dust hang in the air just above the surface;
- cool off-slope breezes exist;
- distant sounds become clearer at night;
- aromas become more distinct (meaning that they are more concentrated near the surface);
- cumulus clouds dissipate in the evening (only applies for fine weather cumulus); and
- smoke, dust or fog descend to low-lying terrain.

Figure 25: Three consecutive inversion nights at a site close to Dalby, Queensland, during November 2019. The three inversions occurred within an hour of sunset and ceased within an hour after sunrise. The tagged wind speeds refer to the 2m level.



Dark red line depicts (vtd10_1) vertical temperature difference: 10m minus 1.25m.
Bright red line temperature at 1.25m (temp_1).
Light grey line is wind speed km/h at 10m (ws_10).
Blue line is wind speed km/h at 2m (ws_2).

How to avoid hazardous inversions

Not all inversions are hazardous but they must be considered to be unless recognised instrumentation exists to identify them.

There really are only two ways to avoid hazardous inversions:

- only spray from one-and-a-half hours after sunrise, and up to one hour before sunset; or
- operate in accordance with advice issued by a recognised inversion monitoring weather system.

Realistically, we can assume the vast majority of growers use 'guesswork' to identify inversions.

Guesswork is a very risky input to critical decisions especially because clues which underpin guesswork do not always eventuate, or they only become obvious hours after hazardous inversions have formed.

A drift hazard warning system to observe hazardous inversions

To minimise the risks of spray drift damage, the Grains Research and Development Corporation (GRDC) led a collaborative research project with the Western Australian Department of Primary Industries and Regional Development (DPIRD) and Cotton Research and Development Corporation (CRDC) to understand the nature of hazardous inversions, and to enable the real-time determination of their presence or absence, along with a forecasting capacity.

Out of that research, GRDC and CRDC have partnered with Goanna Ag to establish the Weather and Networked Data (WAND) (wand.com.au) system, providing the following benefits:

- support grower spray decisions by providing accurate real-time information and forecasts of hazardous inversion conditions;
- mitigate spray drift for economic, community and environmental reasons;
- reduce grower and spray contractor uncertainty of when to spray;
- assist spray contractors to plan the logistics of spray operations and to carry them out efficiently; and
- give growers access to local standard meteorological observations plus inversion and turbulence monitoring.

Additionally, the system data will support:

- agricultural research;
- education;
- health; and
- any entity valuing measures of atmospheric stability, turbulence and dispersion.

A smoke plume rises to the capping inversion before drifting in various directions far into the distance. It remains relatively concentrated even in the distance.

Photo: Theresa Aberkane

The system consists of profiling automatic weather stations (PAWS). It delivers real-time weather data at 10-minute intervals, along with a twenty-four hour forecast, broken into two-hourly segments.

The PAWS have high-quality sensors to report standard weather data. Additionally, PAWS will provide:

- direct measurement of the vertical temperature profile up to 10m above the surface;
- measures of turbulence; and
- accurate wind reports from ultrasonic anemometers at 2m and 10m.

From PAWS data, the stability of the atmosphere and its dispersive characteristics can be calculated.

Groups of towers with correlated data will provide wide area coverage over a region of similar terrain.

Where possible, growers should reject guesswork and operate in accordance with information available from a recognised inversion monitoring weather system. Growers who adopt this system will, in the future, be recognised as the reformers whose practice changes reduced the incidence of damaging drift.

Precautions for night spraying

1. CRITICAL – select spray quality and spray practices to eliminate droplets less than 100µm.
2. Avoid spraying when winds are less than 11km/h between sunset and up to 1.5 hours* after sunrise.
3. Select operating speeds not conducive to the lifting of spray particles behind the machine.
4. Keep boom height low to limit atmospheric exposure and influence on droplets.
5. Do not spray when mist or fog are evident and/or Delta T is less than 2.
6. Use wind meters, flags or smoke devices for wind flow and stability reference.
7. Utilise a recognised inversion monitoring system that provides real-time weather data to growers and spray operators about the presence of temperature inversions.

*1.5 hours is a precaution to limit the possibility of pesticides being lifted by thermals into the eroding and overhead inversion where they may concentrate and be transported in unpredictable directions due to wind shear.

WEATHER AND NETWORKED DATA (WAND)
wand.com.au

6. Recording meteorological conditions

Recording

Wind

Record the average speed and direction over a period of at least a few minutes at 2m height above the ground.

Be aware that on a normal sunny day average wind speed has a gustiness factor typically of about 40 per cent away from the average, with occasional spikes to about 100 per cent. For example, a 10km/h wind typically has peak gusts of about 14km/h and minimums of 6km/h. Wind direction will vary about 30 degrees. For example, an easterly wind will vary rapidly between east-south-east (ESE) and east-north-east (ENE).

Bureau of Meteorology forecasts and observations refer to wind speed and direction averaged over 10 minutes at a height of 10m above ground. The wind recorder is separated from any obstruction by 10 times the obstruction's height. For example, if a tree or shed is 5m high then the recorder must be located at least 50m away.

Simple hand-held meters (above left) can measure temperature, humidity and wind at a height representative of the spray environment. Cab-mounted weather stations (right) can be used to measure and record conditions throughout the spray operation. Source: Graeme Tepper

Temperature and humidity

Record both temperature and humidity (either relative humidity or Delta T) representative of the environment into which sprays are applied. Allow instruments to acclimatise to the environmental conditions before taking measurements.

While there is no mandatory requirement to do so, it may be wise to check and record a representative ground-surface temperature when pesticides are applied over sparse vegetation that provides little shade to the surface. Infrared thermometers are available for this purpose.

Be aware that Bureau of Meteorology temperature and humidity are recorded at approximately 1.25m above the ground in a housing that is shaded and ventilated. At that height large temperature variations occurring in surface air are already well mixed out.

Monitoring meteorological conditions while spraying

To effectively monitor conditions that are important to spray applications requires applicators to be alert to varying conditions. Some variations can be anticipated if the climate of local regions is well known.

Applicators should:

- Acquire knowledge of the **microclimate for the target area**. The Bureau of Meteorology archives half-hourly observations for most of its stations. These records are a valuable resource, which can be mined to gain detailed knowledge of diurnal and hourly variation for the locality of the automatic weather station. Many other authorities and privately set up automatic weather stations exist from which detailed climate analysis can be performed. Before relying on data from any source it is wise to check the quality of the data. Unfortunately, some stations carry poor-quality equipment, lack maintenance and have poor exposure to all prevailing conditions.
- Mine the **knowledge and experience of local landholders**. Locals often know more about variable conditions than statistics ever tell. Use this knowledge and project the terrain influences found in this publication to anticipate conditions you need to be alert to while spraying.

Detailed climate records can be useful to determine:

- diurnal relationships between temperature, humidity, wind flow and stability;
- precursors to local wind flow and typical local wind flows;
- local wind flow regimes associated with varying synoptic air mass types; and
- typical onset and cessation times of temperature inversion conditions.

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Be familiar with the target **field conditions and those of the surrounding area**. Consider what weather variations may occur between dryland farming and irrigated areas or cotton crops adjacent to fallow paddocks. Subtle variations can alter wind-flow pattern, vary the stability of the air and the destination of drift.

Acquire the latest weather forecasts and observations for **as near as possible to the target**. If you have access to a number of automatic weather stations around the target area, then all the better, because you will be able to interpret between these to hone in on a specific area of interest.

In agricultural settings, cup and vane anemometers must be able to withstand harsh paddock environments. Fine dust and moisture with dissolved salts and other contaminants often cause deterioration of moving parts, causing errors in wind speed reports. Birds often destroy plastic models. All mechanical anemometers need to be well maintained; even high quality ones similar to the one displayed in Figure 26.

Ultrasonic sensors have no moving parts and therefore detect low wind speeds very accurately. 2D and 3D models are becoming more common in agricultural settings. These sensors are not so much affected by dust and moisture but still need to be periodically cleaned. The 3D ultrasonic anemometer seen in Figure 27 detects wind in all directions from which turbulent intensity is accurately measured, which is useful for determining rates of spray drift dispersion.

Figure 26: A high quality cup and vane anemometer. Photo: Graeme Tepper

Figure 27: A 3D ultrasonic anemometer. Photo: Graeme Tepper

Useful resources and references

Useful resources

Hazardous Inversion Fact Sheet, grdc.com.au/hazardous-inversion

Meteorological principles influencing pesticide application, grdc.com.au/meteorological-principles-influencing-pesticide-application-national

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Notes

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