WEATHER ESSENTIALS FOR PESTICIDE APPLICATION

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BY GRAEME TEPPER

MicroMeteorology Research and Educational Services

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About the author

Graeme Tepper works with the crop protection industry to convey knowledge of micro-meteorology effects on pesticide application, including the effects of atmospheric stability, surface temperature inversions, cold air drainage wind, evaporation rates and turbulent dispersion.

Research interests

Graeme Tepper is researching the relationships between atmospheric stability, turbulence and temperature inversion hazards to develop resources, including forecasts and observations, to support management decisions aimed at minimising the damage caused by spray drift. The research is funded and supported by the GRDC.

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Introduction

Typically, there is a short window of opportunity to safely and efficiently control pests and diseases in agricultural crops. The opportunity may be shortened by unsuitable weather conditions. It is therefore essential that spray applicators are able to identify and react to weather conditions at a local scale.

Weather Essentials for Pesticide Application aims to help those applying pesticides to understand, observe and interpret weather conditions at the spray target, especially those driven by local microclimates. This knowledge will support the adoption of effective application methods that avoid spray drift.

Particles far smaller than can be seen by the human eye can drift and cause damage many kilometres away from the site of application.

The weather factors that are important to the application of pesticides can be significantly and critically different to conditions indicated by forecasts, maps and off-site weather observations. This is especially true for conditions overnight and into mid-morning when surface inversions are likely to exist and local winds develop. Local winds can transport concentrated volumes of pesticides long distances from the target.

The weather factors that need to be considered before and while applying pesticides are:

- atmospheric stability (including up and down air currents);
- general wind speed, direction and turbulence;
- local wind flows, such as drainage winds caused when air over sloped terrain is cooled by conduction, becomes dense and drains to lower levels, sea breezes and land breezes;
- temperature of the air and the surface; and
- humidity.

Intuitively, the worst weather conditions for spraying are strong winds, high temperature and low humidity. Research has found that spray particles are likely to drift further and in higher concentrations when the atmosphere is stable and where there is a surface temperature inversion.

During the night there is high potential for pesticides to drift at damaging concentrations for long distances in light winds (less than about 12km/h) and gentle breezes (less than about 18km/h) when the temperature is cool, humidity is very high and temperature inversions exist.

Field tests indicate that the greatest drift deposits occurred with relatively high wind speeds, coupled with a temperature inversion and spray in the small droplet spectra (about 200µm) (Bird 1995).

Applicators and advisers need to be able to recognise and respond to all weather factors so that they can make timely adjustments to spray practices to minimise the risk of spray drift and maximise the potential for the pesticide to reach the appropriate target.

PHOTO: PETER COUSINS CONSULTING

An indicator of stable conditions – fog. The inversion over this relatively flat area has most likely been enhanced by cool drainage winds off the distant slopes.

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.

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, operating practices including nozzle, pressure, boom height and speed across the paddock.

The initial driftable percentage may increase if the initial spray sheet which 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 4 times, and by up to 10 times if raised to one metre above the target.

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.

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

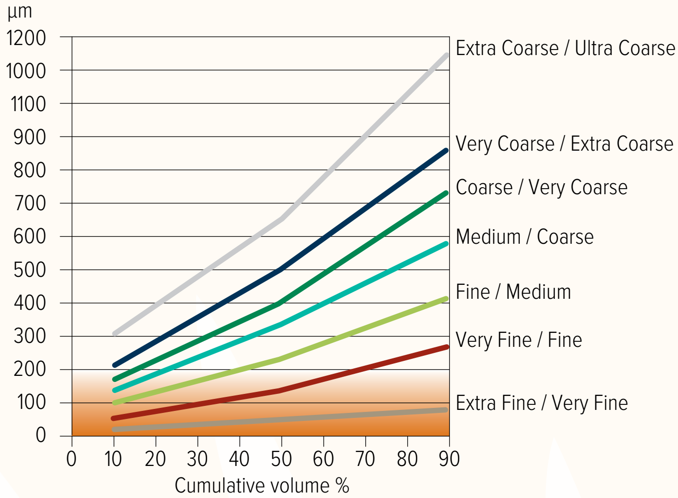
Taking steps to reduce droplet 'air-time' will reduce atmospheric affects and therefore reduce drift risk.

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 700 metres) will dictate long term residence in the atmosphere and transport out of the local region.

1 Droplets less than 150 microns are highly susceptible to being carried away by the wind and to rapidly evaporate. Droplets larger than 200 microns should in theory make it to the target. However, droplets even larger than 200 micron can rapidly reduce in size and drift when not applied carefully and/or when they are exposed to hot and dry conditions often experienced over sparsely vegetated paddocks in summer.
Droplets and particles less than 50µm and vapours are extremely drift prone. They are of major concern for night-time spraying, when very stable conditions exist. They tend to float in layers of air during very stable conditions and are unlikely to reach the surface under their own weight. Small turbulent fluctuations can keep particles less than 50µm and vapours suspended for long periods near the surface when very stable conditions (strong 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).

FIGURE 1 Spray nozzle classification by droplet spectra example reference graph



Droplets less than 200µm are quite drift-prone, especially in summer when evaporation can rapidly reduce their diameter and weight. Generally 100µm droplets are highly drift-prone.

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% of total spray volume to the atmosphere.
The 50% value for all spray qualities shown in above graph is equivalent to the volume median diameter (VMD). A droplet dimension which indicates 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

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 very stable conditions with laminar wind flow (typical of drainage winds) the products of evaporation or volatilization 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. Typical aerosols are tiny haze particles, fog droplets, smoke particles, pollens, dust and salts. Smog is a good example of pollutants attached or absorbed into such aerosols.

WEATHER GUIDELINES FOR PESTICIDE APPLICATION

Spray when wind is steady and ideally more than 5km/h and up to 15km/h (see page 10)

Very light winds (less than about 7km/h) are often inconsistent in strength and direction. They frequently accompany two of the most adverse spraying conditions: strong thermals and strong 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.
- As inversions lack turbulence, they can trap and concentrate suspended spray materials in layers. Airborne pesticides can be transported within the layers at high concentrations for long distances by light winds and gentle breezes.
- Winds less than 5km/h are unsuitable for spraying because they are highly likely to be variable in direction and thus the direction of spray drift would be impossible to determine and the safety of downwind receptors compromised. Most instruments will not accurately detect winds less than 5km/h. Winds of about 6km/h are required for an observer to feel the wind on the 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 and dispersed into the atmosphere and may travel long distances.

Avoid spraying in temperatures above 30°C (see page 16)

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 (see page 18)

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.

PHOTO: FRANK TAYLOR

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: GRAEME TEPPER

An indicator of unstable conditions – cumulus clouds.

- 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 inversion conditions exist (see page 20)

Temperature inversions lack turbulence. This can lead to high concentrations of airborne pesticides being transported close to the surface in light and variable winds to destinations that cannot usually be predetermined.

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10 tips for reducing spray drift

FOR MORE INFORMATION:

Spray Application Manual for Grain Growers: www.grdc.com.au/resources-and-publications/grownotes/technical

1	Choose all products in the tank mix carefully, which includes the choice of active ingredient, the formulation type and the adjuvant used. Tools are now available to assess the impact of tank mix on the percentage of drift-prone droplets produced.
2	Understand how product uptake and translocation may impact on 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. Use water-sensitive paper and the Snapcard app to assess the impact of coarser spray qualities on coverage at the target.
4	Always expect that surface temperature inversions will form later in the day, as sunset approaches, and that they are likely to persist overnight and beyond sunrise on many occasions. If the spray operator cannot determine that an inversion is not present, no spraying should occur.
5	Use weather forecasting information to plan the application. BoM meteograms and forecasting websites can provide information on likely wind speed and direction for 5 to 7 days in advance of the intended day of spraying. Pay close attention to variations between predicted maximum and minimum temperatures above 5°C to 7°C, Delta T values below 2, low overnight wind speeds (less than 11km/h) and predictions of dew or frost as these all indicate the likely presence of a surface inversion.
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 a 50cm nozzle spacing (this 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 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.

1. Atmospheric stability

"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" and *"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."*

– D. R. Miller, 2001.

Smoke from home fires trapped by very 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.

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 (page 12) to provide knowledge of three-dimensional turbulence intensity that has critical influence on deposition and dispersion of drift.

Effects of stability

Atmospheric stability is one of the most important factors in determining spray dispersion.

– Miller et al., 2012.

Stability has significant effect on spray drift at the time of application, on post volatilisation, and on the final concentration of deposits" and *"The concentration of the spray plume and volume that deposits to the surface is dependent on atmospheric dispersion.*

– Majewski and Capel, 1995.

Some of the more mysterious cases of off-target damage can be attributed to stability, or more specifically, a concentration of fine droplets in a stable atmospheric layer

– Thistle et al., 1998.

STATES OF STABILITY (FIGURE 2)

Mildly unstable conditions (air is slightly warmer at the surface – cooler air above the surface) are associated with fine-weather cumulus clouds and gentle lifting of plumes away from the surface and slow-widespread dispersion.

Very unstable conditions (hot air at the surface – cooler air above the surface) are typically associated with whirly winds, thunderstorms, tornadoes and widespread rapid lifting of plumes away from the surface and rapid-widespread dispersion. This condition combined with strong winds and wind shear is associated with dust storms.

Neutral conditions (no change of temperature with height) do not promote or restrict dispersion and are considered to be the ideal spray conditions. In combination with wind, plumes fan out in a cone-like pattern that intercepts the surface – thereby promoting deposition and minimal drift. Unfortunately, neutral conditions rarely occur or just fleetingly occur in conditions otherwise considered ideal for spraying.

Mildly stable conditions (cool air at the surface – warmer air above the surface) closely mimic neutral conditions and are associated with mild suppression of dispersion.

Very stable conditions (cold air at the surface – warm air above the surface) associated with strong inversions greatly suppress dispersion and causes plumes to drift in thin layers near the surface at quite high concentrations. This condition combined with light winds and minimal wind shear is known to be related to widespread damaging drift.

One simplified indicator of dynamic stability is the stability ratio (SR). An example in Figure 3 shows (1) that stable conditions (inversion) can exist with wind speeds exceeding 11km/h; and (2) the variability of stability throughout the period – therefore the inversion intensity and associated hazards.

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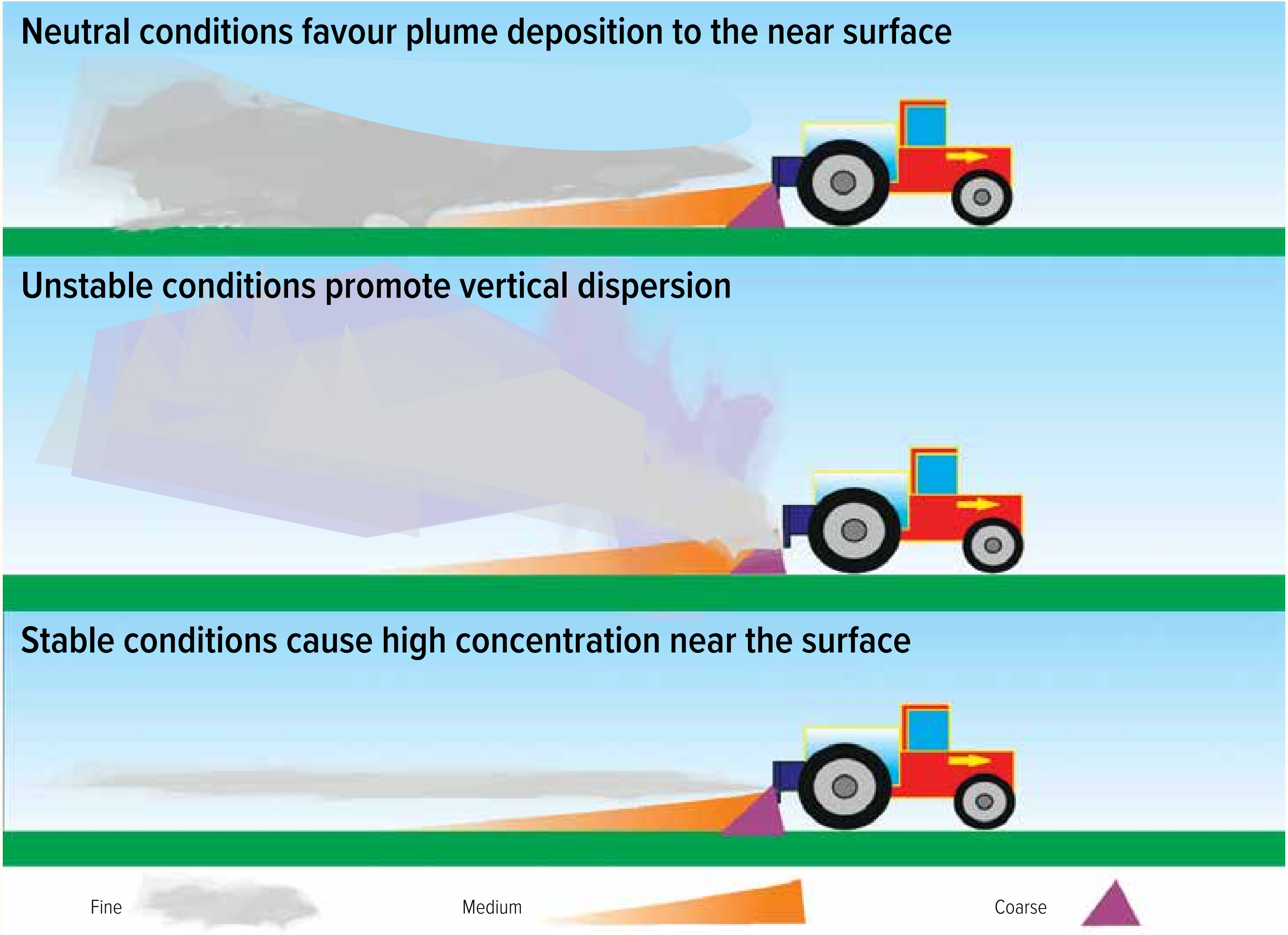
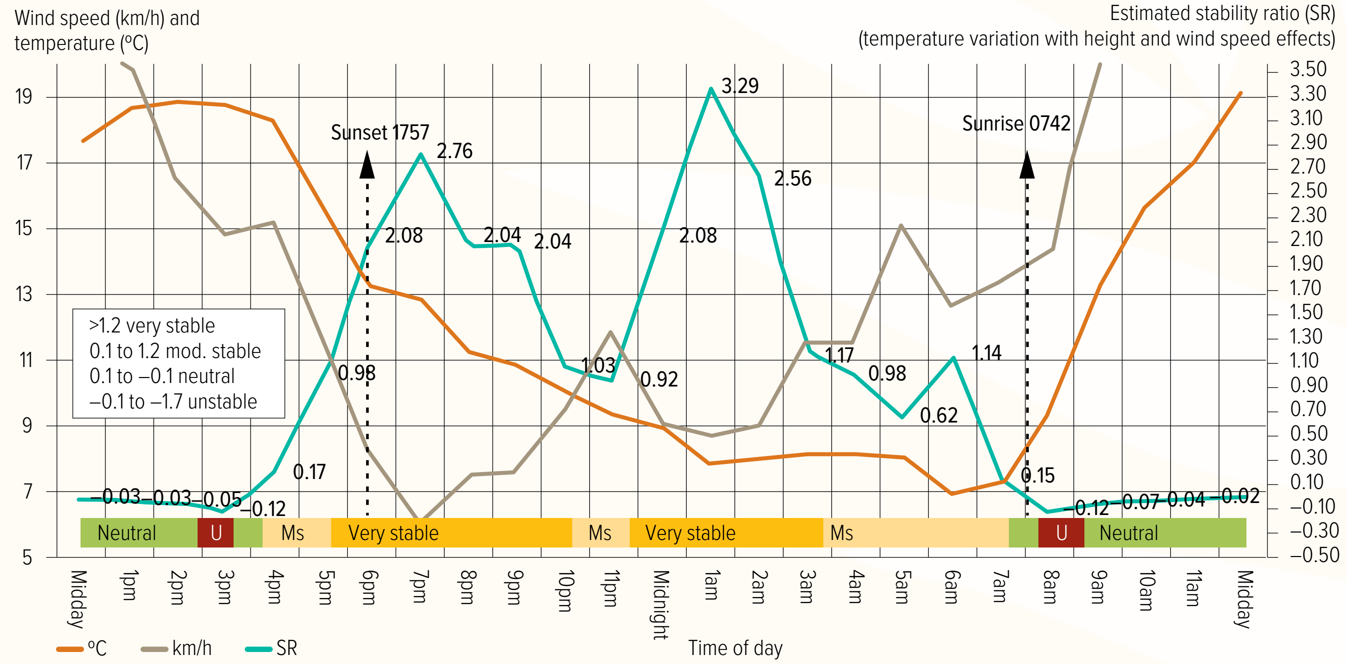
FIGURE 2 Three common states of atmospheric stability and their relationship to spray application.



SOURCE: GRAEME TEPPER

FIGURE 3 The importance of monitoring weather during spray operations: an estimated stability ratio (SR). In this case, the inversion had eroded to about 70m by 8:30am – a capping inversion with top at 208m remained until about 10:30am.



Stability variations and estimated stability ratios over 24 hours. The temperature and wind traces show the relationship between stability, wind speed and temperature at the surface. Left to right neutral conditions initially dominate due to moderately strong winds, followed by a short period of unstable (U) conditions due mainly to a drop in wind speed. This was followed by a short period of neutral through to the transition to moderately stable (Ms) and very stable (inversion) conditions. The inversion weakens to moderately stable conditions due to periodic wind speed increases. By about 3:30am synoptic flow strengthens and stability tends to moderate then neutral, unstable and neutral again.

SOURCE: GRAEME TEPPER, SCADDAN/ESPERANCE, 28-29 MAY 2003

2. Wind

Wind is simply air in three-dimensional motion.

Many factors lead to spray drift but ultimately it is caused by horizontal and vertical winds that promote the transfer of pesticides into the atmosphere. For most purposes, horizontal wind can be adequately described as an average of the speed and direction of air flowing parallel to the Earth's surface. Bureau of Meteorology forecasts and observations refer to horizontal wind speed and direction averaged over 10 minutes at 10 metres above the ground (Figure 4).

When considering pesticide application the most important vertical winds are those associated with thermals. Vertical winds can significantly affect the volume of pesticides swept off site.

Three-dimensional motion determines:

- airborne pesticide concentrations;
- the vertical distribution of airborne pesticides;
- direction and distance of pesticide transport; and
- pesticide deposition.

Air primarily flows in response to adjacent pressure differences (highs to lows), heating (thermals) and cooling (drainage winds). As air flows over the surface it is deflected by obstacles and slowed by friction. Consequently, near the surface it breaks down into a series of turbulent eddies that lead to rapid fluctuations in wind speed and direction.

Winds relevant to pesticide application are:

- synoptic winds – horizontal surface winds, initiated by air flow from high to low pressure. Isobar spacing illustrated on weather maps can be used as a general guide to determine wind speed and direction; and
- local winds – up, down or horizontal winds that flow over short distances, initiated by unequal heating and cooling of the ground and by the shape and features of the paddock and the regional. Gravity has a major impact on the destination of air being cooled on slopes. Surface heating has a major influence on the strength of rising-air currents. Local winds cannot be determined from isobar spacing.

SPRAY GUIDELINES

- Spray only when wind direction is away from sensitive areas (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 calm or less than 5km/h or at any wind speed where constancy in direction is not assured.

High wind speed (above 15 km/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 and breezes 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 unless thermals exist.

Also refer to page 24 – Precautions for night spraying.

TURBULENCE

Turbulence is the specific feature of wind flow, both horizontal and vertical, that determines the concentration and dilution of airborne pesticides. It consists of rolling motions (eddies) in the airflow; larger rolls generate greater turbulence and greatest dispersion of airborne pesticides.

Turbulence intensity is regulated by atmospheric stability and is usually suppressed at night and enhanced during the day (see atmospheric stability, page 8).

A lack of turbulence leads to airborne pesticides floating at high concentrations near the surface and high risk of adverse drift effects. This is the situation during a surface temperature inversion.

FIGURE 4 Bureau of Meteorology wind chart. Red lines trace out a continuous and instantaneous wind recording. Wind speed variability often has a gustiness factor (highs and lows) of 40% during sunlight hours (less at night). There can be wind direction variations of about 30° during sunny conditions (less at night). Average values, typical of those reported by observations and forecasts, are depicted as white lines.

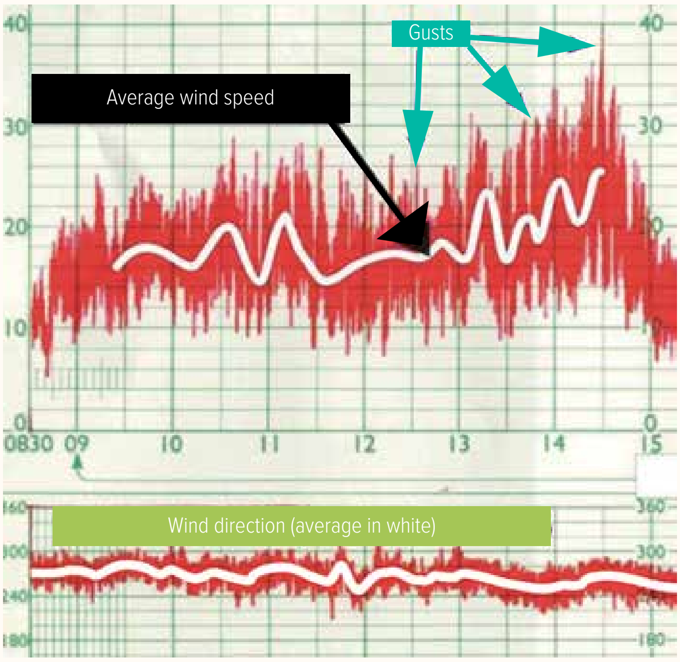
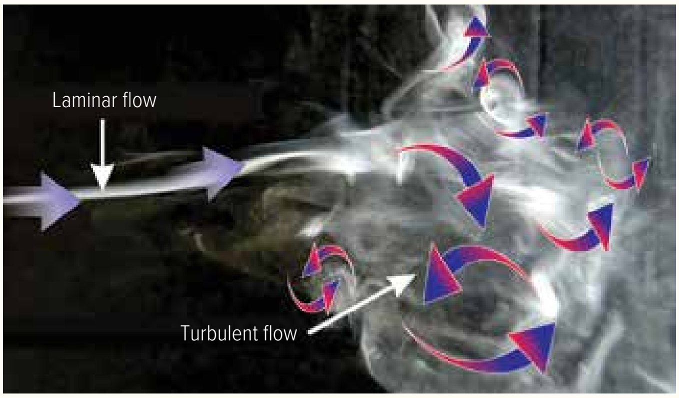
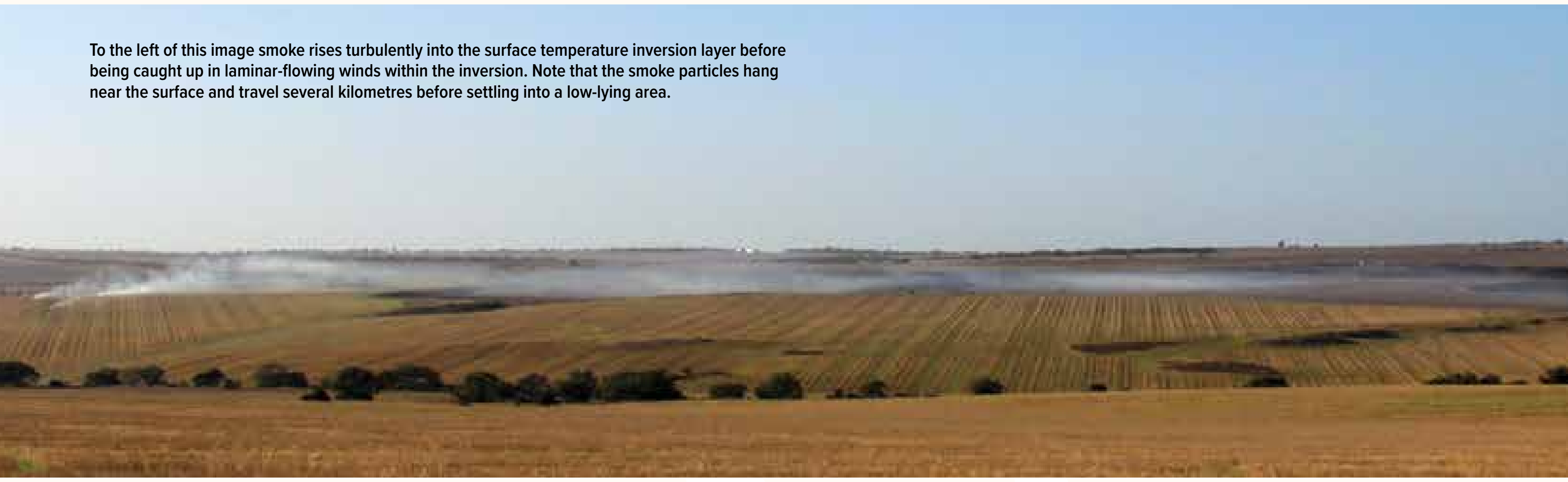


FIGURE 5 Turbulence.



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

PHOTO: BILL CAMPBELL



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 settling into a low-lying area.

Intense turbulence leads to rapid dispersion of airborne pesticides both horizontally and vertically, taking larger particles down to the surface and lifting smaller particles high into the atmosphere (Figure 5). Spray drift will occur but particles will be dispersed, diluting the pesticide concentration and 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, it also acts to keep airborne pesticides in suspension for long periods.

SYNOPTIC WINDS

Synoptic winds are the winds usually referred to in weather forecasts (sea breezes being an exception for coastal regions).

Synoptic winds are those resulting from air flowing in response to pressure-gradient forces that build up between areas of high and low pressure over several hundreds or thousands of kilometres. The greater the pressure difference, the greater is the pressure-gradient force and hence the stronger are the winds.

It might be expected that synoptic winds should flow directly across isobars from high to low pressure but this is rarely the case. Instead, the observed behaviour is that the synoptic winds flow slightly across isobars and exhibit anti-clockwise spiralling of wind out of high-pressure systems and clockwise spiralling of wind into low-pressure systems (this is in the southern hemisphere; in the northern hemisphere winds spiral clockwise out of high-pressure systems and anti-clockwise into low-pressure systems).

The pressure/wind relationship can be seen by comparing isobar configuration to winds (Figure 7). These charts (minus the arrows) are available from the Bureau of Meteorology.

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 usually on a small scale, more pronounced after sunset and decline in influence after sunrise.

Local wind flows are caused by:

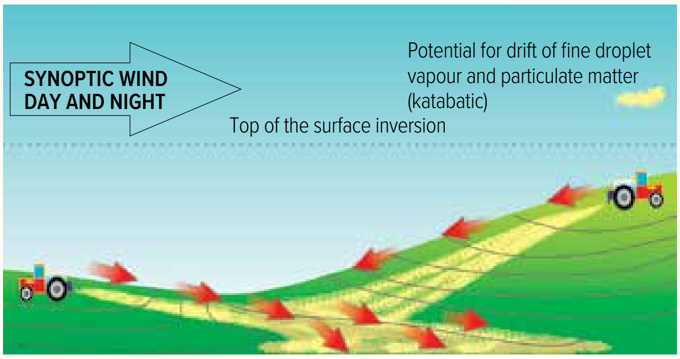
- on-slope cooling (drainage winds – Figure 6);
- on-slope heating (anabatic winds – Figure 8);
- terrain blocking (blocked winds – Figure 9);
- differential heating (sea and land breezes – Figures 10 and 11);
- cool air falling downslope (downslope winds – Figure 12);
- excessive heating (thermals – Figure 13); and
- density currents (far-inland sea breezes).

Measuring local winds

Because local winds are short-lived and variable, frequent in-paddock observations are required to track variations.

While sophisticated instruments can be used to track variations, simple methods are often useful. Ribbons attached to the end of the boom or on fencelines, smoke pots or a smoking device fitted to the tractor's exhaust can all help indicate wind strength and direction. In turn, such observations indicate if the atmosphere has become stable (see atmospheric stability, page 8) and the wind has become less turbulent. Handheld wind meters should be held at the height of the boomspray for wind measurement.

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

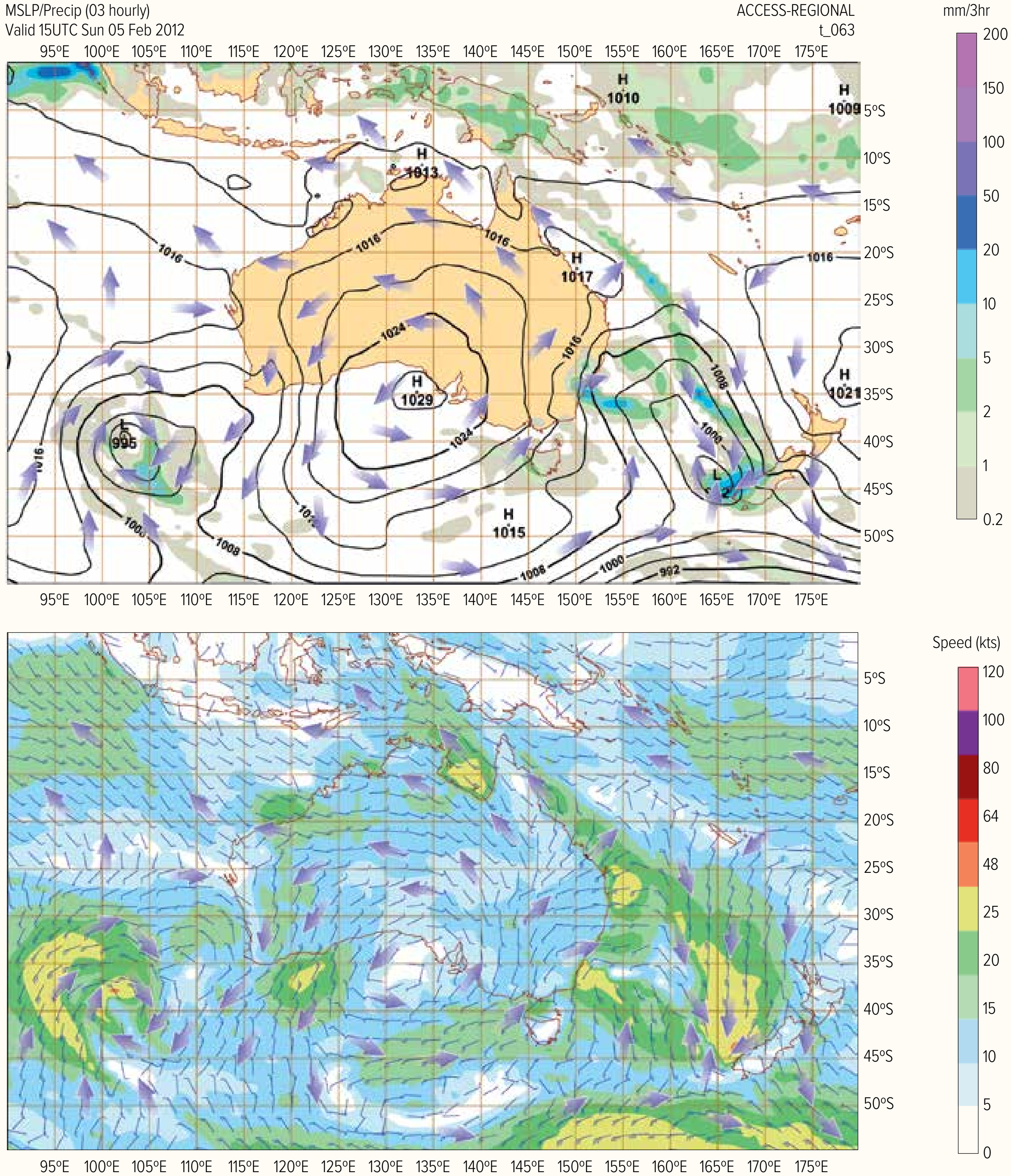
WIND SHEAR

When wind direction and speed change with altitude 'wind shear' exists (Figure 14, page 14). Wind shear can lead to airborne pesticides being transported in directions other than what the surface direction indicates.

Applicators should be wary of wind-shear effects from sunrise and up to about an hour-and-a-half after sunrise when a surface temperature inversion is progressively eroding (Figure 15, page 14).

To anticipate wind shear, applicators need to compare the overriding synoptic wind flow to that occurring at the surface.

FIGURE 7 The mean sea-level pressure pattern (synoptic chart) on the top generates surface (10 metres above the ground) winds as illustrated by the chart on the bottom.

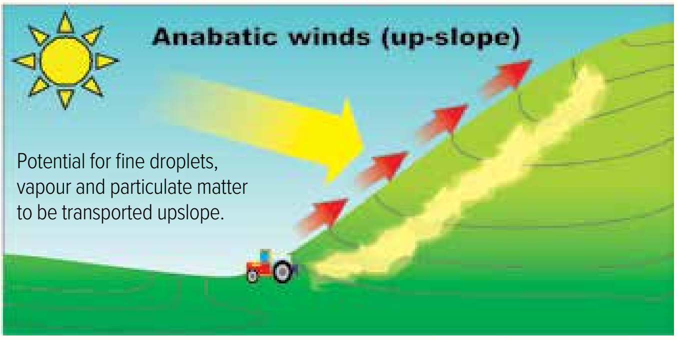


SOURCE: BUREAU OF METEOROLOGY

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 14, page 14).

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.

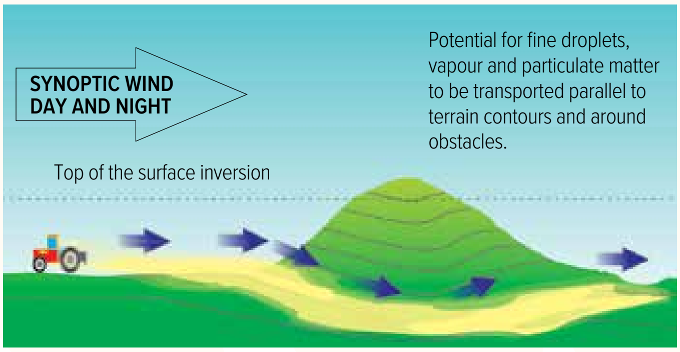
FIGURE 8 Anabatic winds (up-slope).



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

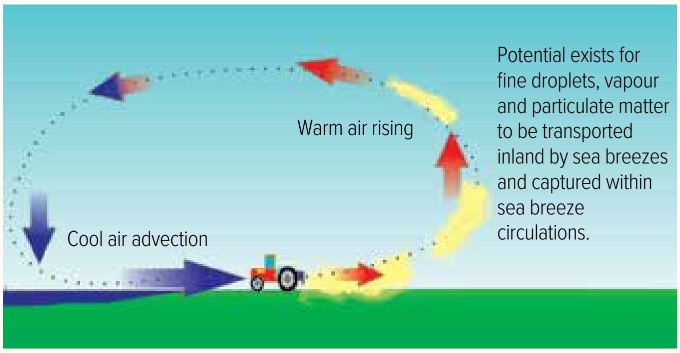
FIGURE 9 Blocked winds and contour wind flow.



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 (e.g. 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 distant drift and widespread damage.

SOURCE: GRAEME TEPPER

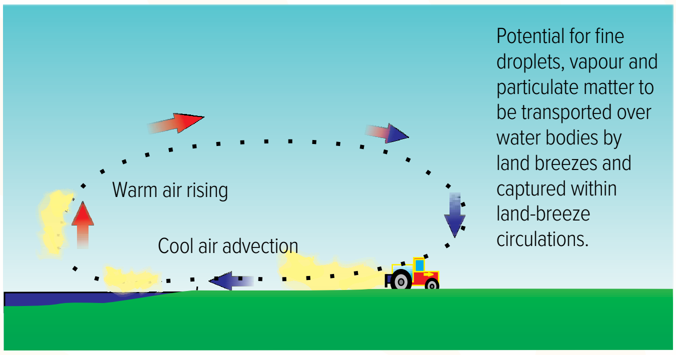
FIGURE 10 Sea breeze circulation.



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 (e.g. 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

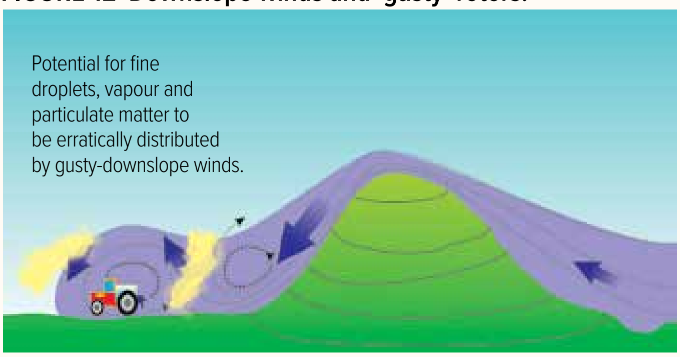
FIGURE 11 Land breeze circulation.



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 12 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 13 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

DIURNAL VARIATION OF WIND

Diurnal variations in wind speed and gustiness are related to temperature and atmospheric stability (Figures 16 and 17).

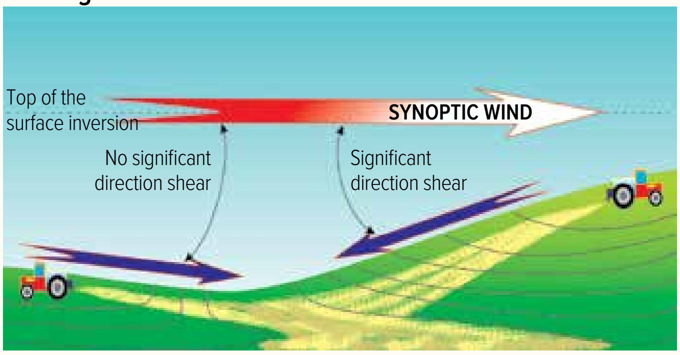
Evening and overnight decrease of wind speed and gustiness

In the afternoon and evening, synoptic wind speed tends to decrease in response to increasing stability of the atmosphere along with a tendency for the synoptic flow to lift off the surface (decouple). As the synoptic wind decouples from the surface it is frequently replaced by local winds, most commonly cool drainage winds or blocked winds (Figures 6 and 9). Drainage winds generally flow downhill while blocked winds generally flow parallel to topographic contours.

The overnight reduction of wind speed and turbulence is primarily caused by:

- rapid cooling of the surface air;
- a trend to increased stability of the atmosphere; and
- ultimately a strong temperature inversion.

FIGURE 14 Synoptic wind direction compared with local 'drainage wind' direction.

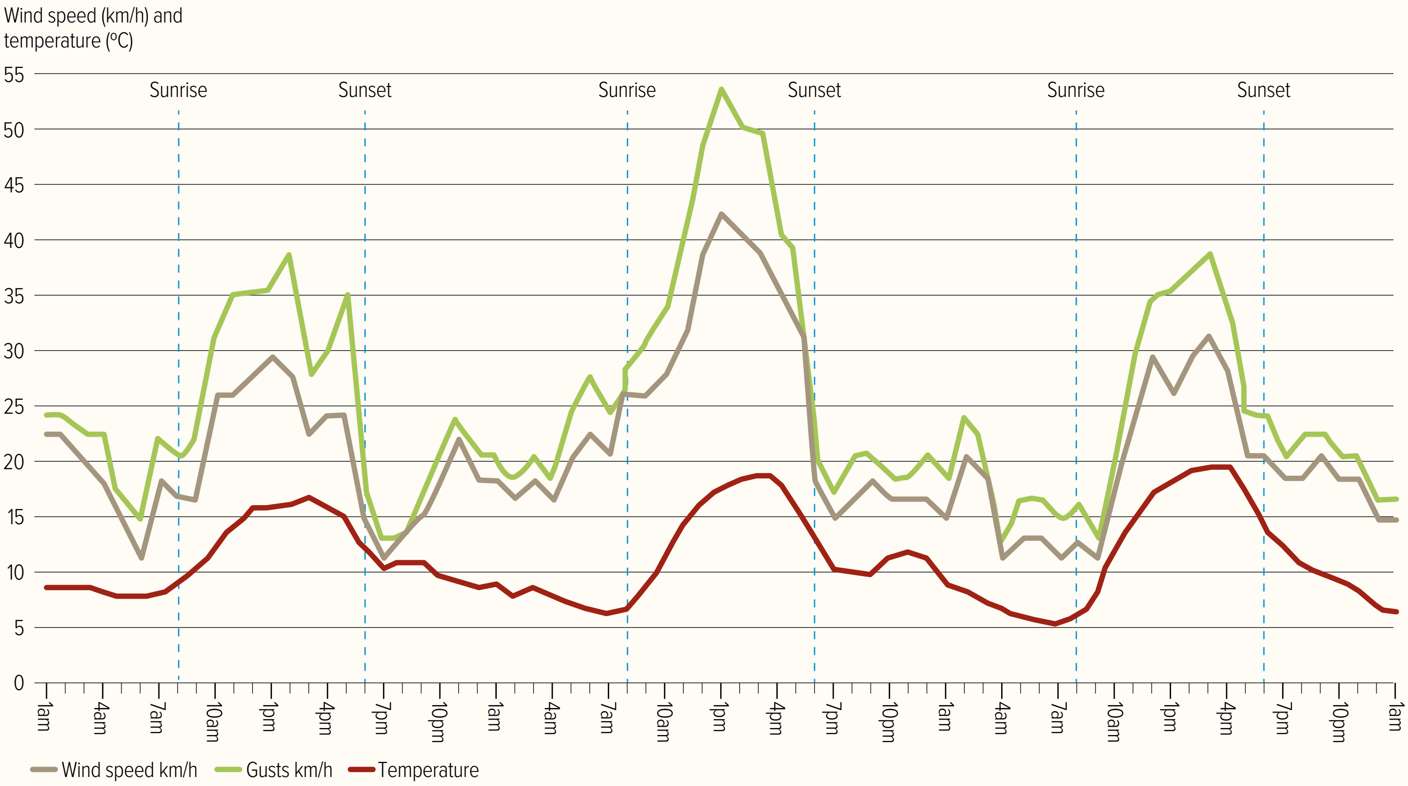


The variation between the direction of synoptic winds flowing above the surface and the drainage winds illustrates the difference between a sheared and non-sheared environment. SOURCE: GRAEME TEPPER

FIGURE 15 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 16 Relationship between temperature, wind speed and gustiness over a three-day period, Horsham, Victoria, 24 to 26 May 2007



Vertical axis indicates km/h and degrees. The horizontal axis indicates time of day.
Maximum wind speed and gustiness are directly related to maximum temperature (the most unstable period of the day).
Minimum wind speed and gustiness are directly related to minimum temperature (the most stable period of the night).
A rough idea of atmospheric turbulence and stability can be gained by observing the difference between actual wind speed and gusts.
The greater the difference, the more intense is the turbulence and the more unstable is the atmosphere. SOURCE: GRAEME TEPPER

The reduction in surface wind speed is:

- often accompanied by an anticlockwise (southern hemisphere) directional variation of the surface wind. Within an hour or two of sunrise the wind direction usually reverts to that expected of the synoptic situation. This turning may be important in planning buffer zones;
- mirrored by an increase in wind speed and directional variations (wind shear) just above the surface, usually with a maximum speed near the top of the inversion; and
- sometimes accompanied by sporadic turbulence and periodic switches in wind direction at the surface.

Early morning increase in wind speed and gustiness

Wind speed and gustiness often increase soon after sunrise due to surface inversion decay (see surface temperature inversion, page 20) and the return of synoptic winds to the surface.

During the transition, wind speed and direction can be significantly different at the surface compared with just a few metres above the surface. Airborne pesticides caught up in this wind shear can be transported in unexpected directions.

A WORD ABOUT EQUIPMENT SPEED OF TRAVEL

From Bill Gordon, spray application specialist

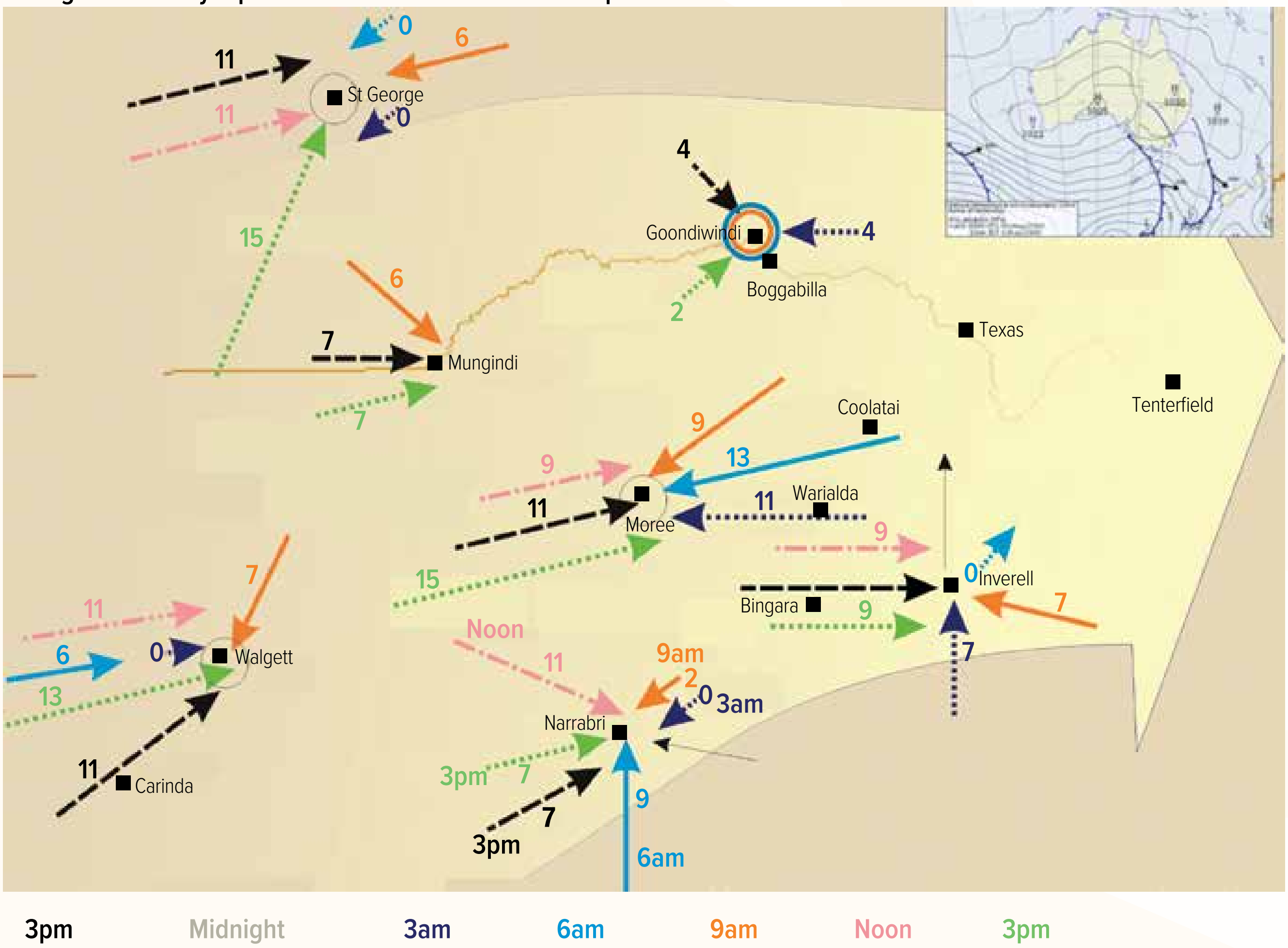
Both faster travel speeds and greater release heights increase the amount of chemical left in the air during spraying operations. This is because turbulent winds behind the machine increase.

If travelling faster or raising the boom above the height required for a double overlap of the spray patterns, more consideration must be given to nozzles and other parameters that reduce the airborne fraction of the spray.

Reducing the airborne fraction can be achieved by:

- using a coarser spray quality (the coarsest that will provide efficacy);
- nozzles with narrower fan angles;
- alternating offset nozzles (forward and backwards);
- using nozzles with higher exit velocities;
- preventing boom bounce and yawing (whipping); and
- selecting adjuvants that do not increase the driftable fraction.

FIGURE 17 Surface wind variations between 3pm on 5 May 2008 and 3pm on 6 May 2008. The large arrow indicates the overriding SSW to W synoptic wind direction for the 24-hour period.



While the synoptic wind flow is consistently from the west to south-west the arrows show the changing direction and strength of surface wind over a 24-hour period. Longer arrows represent stronger winds. The variations in surface wind flow are typical of those experienced when inversions form overnight and local winds develop regardless of the overriding synoptic wind flow.

SOURCE: GRAEME TEPPER

3. Temperature

For a spray applicator, the temperature of the air into which pesticides are sprayed and the temperature of the surface over which they are applied are important.

Air and surface temperature have direct influence on the deposition of pesticides and on the rate at which pesticides volatilise from soil and plant surfaces (see Volatilisation – be aware of surface temperature, page 17). Increasing temperature usually decreases the relative humidity of the air and thus increases the evaporation rate of the aqueous component of pesticide droplets.

The difference between the surface temperature and that of the air immediately above the surface is also very important. This is because it dictates the stability of the atmosphere and in turn, affects the potential for airborne pesticides to rise and dilute or remain concentrated near the surface.

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.

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 (Figure 18).

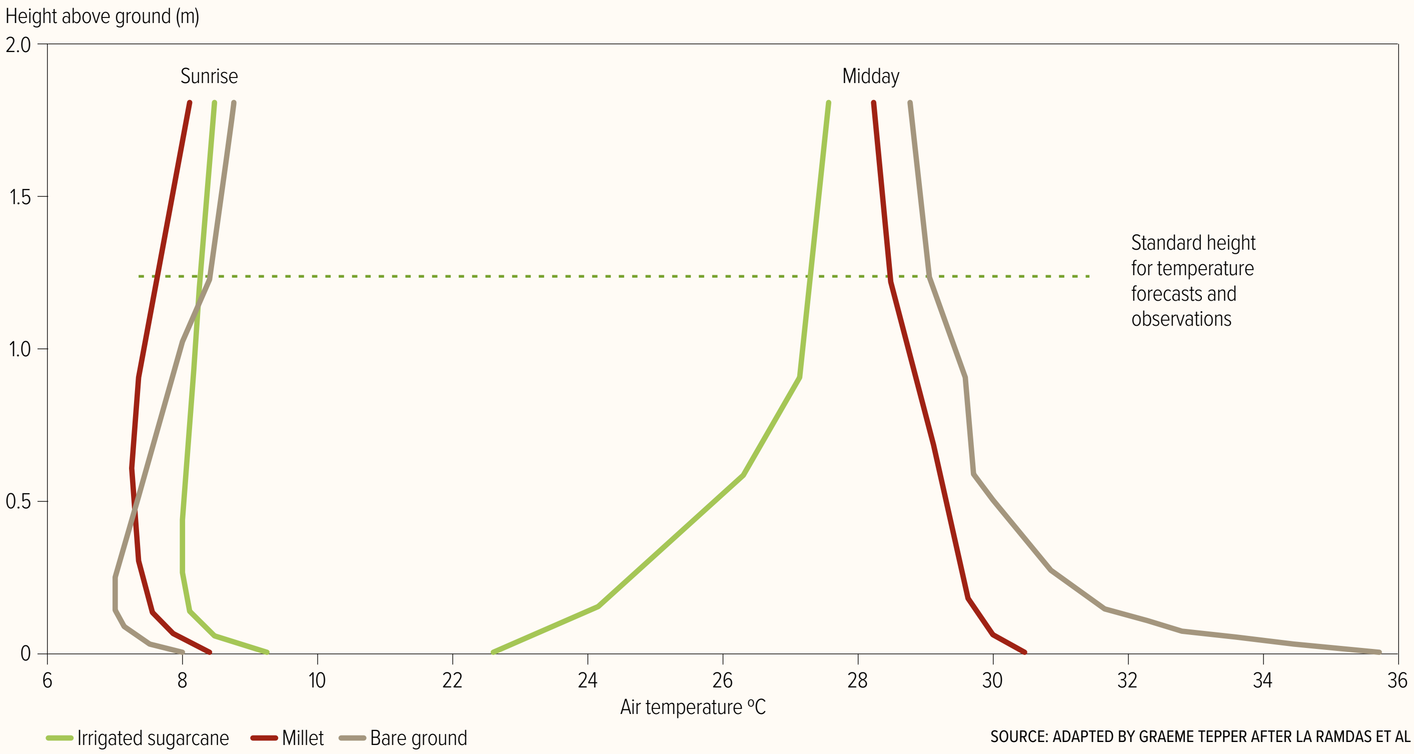
A common guideline is to spray only when air temperature is less than 30°C. However, soil temperature, especially in summer with sparse vegetation, can be considerably hotter than the air.

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 19).

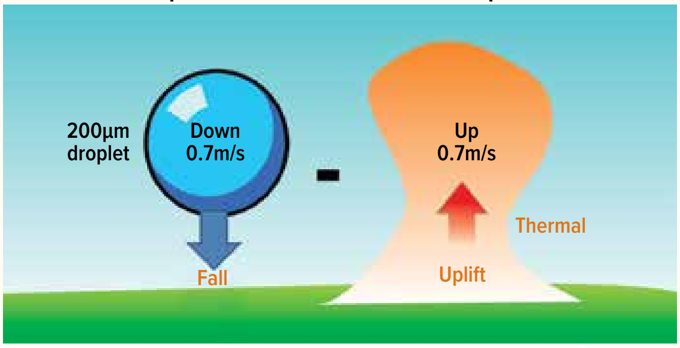
One solution is to use the largest droplets possible while maintaining efficacy and to operate the machine in a configuration and at a speed to minimise the production of drift-prone droplets.

FIGURE 18 Temperature profiles illustrating the effects of vegetation and bare ground on the variability of the vertical temperature profile within the first few metres of the surface. Note that the air temperature at 1.25m barely changes while surface temperatures change a great deal in the six-hour period.



SOURCE: ADAPTED BY GRAEME TEPPER AFTER LA RAMDAS ET AL

FIGURE 19 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

DIURNAL TEMPERATURE VARIATIONS

The temperature within the first few metres of the surface varies rapidly compared with the air temperature above. This leads to changes in stability causing:

- during the day – a deep mixed layer to develop into which airborne pesticides can dilute (Figure 20); and
- at night – wind speed tends to be lower than during the day, so little or no mixing occurs in a shallow layer that is generally close to the surface in which airborne pesticides tend to be held at high concentrations (Figure 21).

Between sunset and sunrise surface temperature inversions often exist. This is where the temperature gradient is reversed so that the temperature at ground level is cooler than that of the air above.

Inversions suppress turbulence, so airborne pesticides become concentrated in a layer close to the surface. 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.

This combination of factors makes surface temperature inversion conditions especially hazardous for pesticide application.

VOLATILISATION – BE AWARE OF SURFACE TEMPERATURE

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

At normal application temperatures amine and sodium salt formulations of phenoxy herbicides do not produce volatile vapours, whereas ester formulations always produce volatile vapours (Victorian DPI, 2010).

Both high volatile esters (HVE) (ethyl, butyl and isobutyl esters) and low volatile esters (LVE) (hexyl, octyl and so on) are capable of producing volatile vapours. Amine formulations may produce volatile vapours if the temperature rises to 50°C (Victorian DPI, 2010).

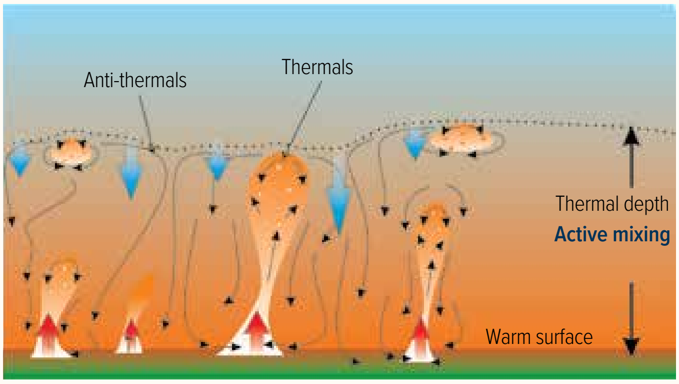
Higher temperature increases volatilisation rates and promotes the transfer of vapours into the atmosphere from plants and soil. Volatilisation may represent a major dissipation pathway for pesticides applied to soil or crops. It accounts for up to 90 per cent of the application dose in some cases (Bedos, 2002).

High concentrations of drifting vapour are most likely to occur:

- from sunset to an hour or so after sunrise, when surface inversions and drainage winds restrict dispersion of vapours at the surface; and
- in the early morning, when weak thermals lift vapour into a low-level capping inversion (Figure 27, page 23).

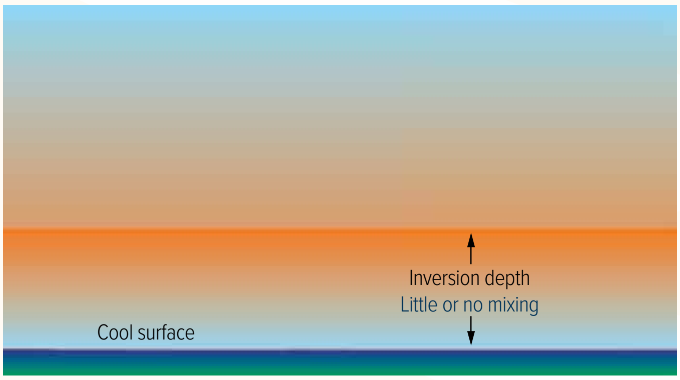
Vapour lifted by thermals has the potential to be concentrated by the cap and vapours may later descend to the surface some distance from the application site.

FIGURE 20 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 21 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

4. Evaporation

The rate at which spray droplets evaporate is mainly determined by the amount of water vapour that the air can absorb, the droplet volume compared with its exposed surface, 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 22).

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 23).

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.

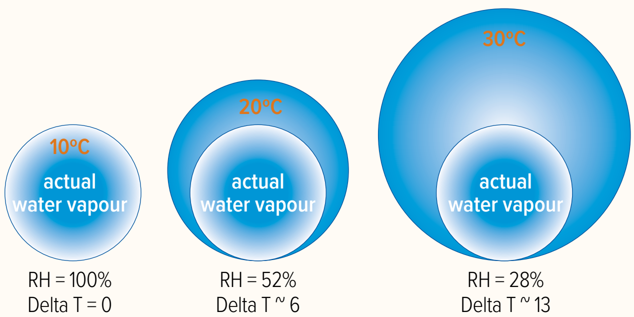
Relevance for spraying

How rapidly a droplet evaporates is dependent on the aqueous component of the droplets because it is only the aqueous component that actually evaporates.

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)

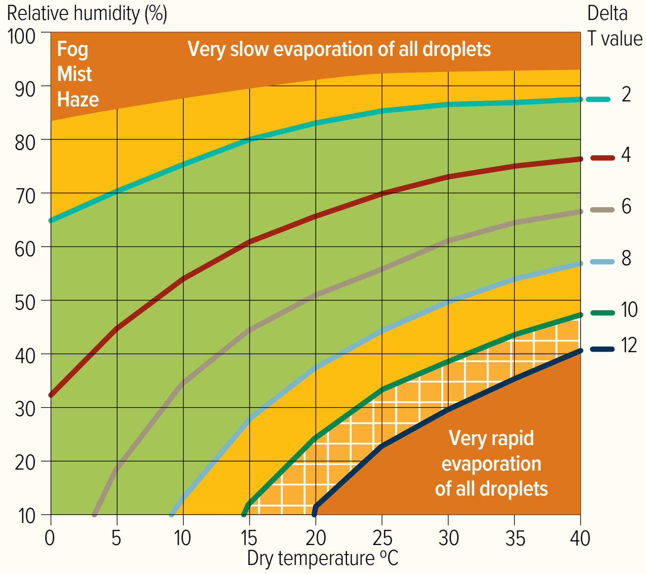
Partial evaporation of the aqueous component of droplets before reaching the target leads to ever-decreasing droplet size and higher concentrated droplets, slower fall rates and high potential for drift.

FIGURE 22 A depiction of one air parcel undergoing a temperature change while the amount of moisture remains the same.



SOURCE: GRAEME TEPPER

FIGURE 23 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 12



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

NEVER SPRAY DURING A SURFACE TEMPERATURE INVERSION

SOURCE: ADAPTED BY GRAEME TEPPER (2012) ORIGINALLY SOURCED FROM NUFARM'S SPRAYWISE DECISIONS CHART (2012)

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.

No evaporation of the aqueous component of small droplets already in suspension can lead to unacceptably long life and long distant 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 remerge 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);
- rainout (washout);
- in rain (within droplets);
- fog (droplet settling); and
- air currents (downward flow).

PHOTO: EMMA LEONARD

Spraying into a very humid environment.

There is evidence that spraying in foggy conditions can lead to significant drift issues not yet completely understood. Major drift incidences have been reported in Australia after application in foggy conditions. Scientific studies raise concerns that:

- small droplets not immediately falling to the surface tend not to evaporate and may act as nuclei for fog droplets;
- chemical reactions in fog can result in compounds sometimes more toxic than the original pesticide. Glotfelty et al, 2000, found that "a variety of pesticides and their toxic alteration products are present in fog, and that they occasionally reach high concentrations relative to reported rainwater concentrations"; and
- settling of contaminated fog droplets bound with pesticides may fall out over wide areas.

According to Seiber (2002): "The scavenging of particle bound pesticides and pesticide vapours into atmospheric moisture (cloud and fogwater, rain and snow) is a potentially major sink for airborne pesticides. Concentrations of some pesticides in fogwater can significantly exceed those expected based upon vapour-water distribution coefficients. Fogwater deposition has been implicated as a source of inadvertent residues to non-target foliage, and of high-risk exposures for raptors residing in and around treated areas".

5. Surface temperature inversions

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

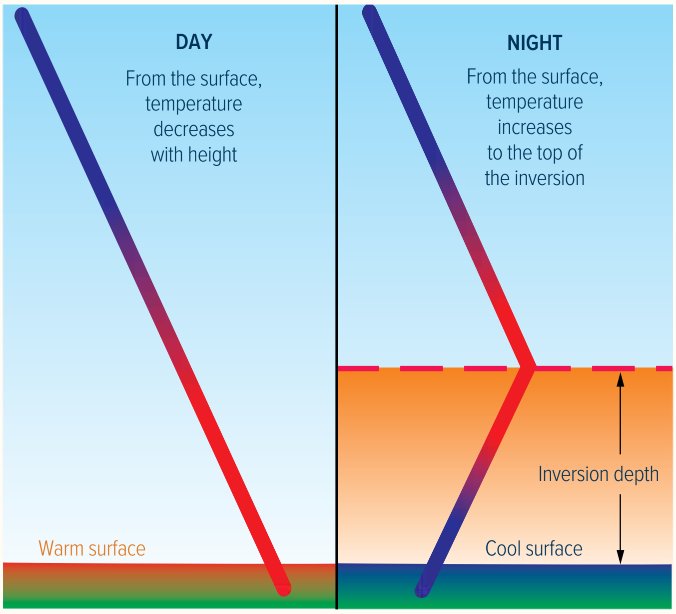
PHOTO: BILL GORDON

Widespread damaging drift can be caused by spraying when a strong inversion exists.

An inversion occurs when the temperature increases with height (Figure 24). It is generally believed that surface inversions are strongest and most hazardous close to sunrise. However, this is often not the case. Instead, inversion hazard is often highest from dusk to a few hours after sunset and weak at sunrise. Sometimes the hazard level of inversion varies rapidly between dusk and a few hours after sunrise.

The degree to which an inversion is hazardous depends on the combined effects of the vertical temperature difference and turbulence intensity (Figure 5, page 10). Both are highly dependent on:

FIGURE 24 Typical vertical temperature profiles for a point in time during the night and day. The day profile typically cools with height and the night profile typically warms with height to a depth which constitutes the surface temperature inversion layer. The point where the temperature stops increasing is the top of the surface temperature inversion layer.



SOURCE: GRAEME TEPPER

- ground cooling rate;
- wind speed variations;
- how rough the underlying surface is;
- the intermittent 'blanketing' effects of transient cloud; and
- drainage winds injecting cool air into the base of the inversion.

GRDC research shows that weak inversions pose little risk or hazard for spraying whereas strong inversions (those occurring in dynamically stable conditions (page 8)) are the likely culprits of high concentrations of pesticides drifting near the surface for long distances. In dynamically stable conditions drifting material may remain airborne for a long time when trapped within laminar 'conduits', similar to the layered structures shown over the canola crop (above).

Many products' labels specifically forbid spraying during surface inversions.

The difficult-to-predict inversion variations requires that spray applicators continuously monitor conditions while spraying at night for clues to inversion occurrence and intensity. Not detecting an inversion and degree of hazard may lead to widespread damaging drift.

Identification of inversion occurrence and the threats they pose to spray operations can best be determined by establishing profiling automatic weather stations, which are designed to accurately detect the variables essential to providing timely advice to applicators.

INVERSION MICROCLIMATE

A strong surface temperature inversion can be likened to a dome of air over the ground that is cut off and largely insulated from the surrounding atmosphere.

Being isolated, the surface temperature inversion develops a microclimate in which winds in particular can significantly differ from the broader weather pattern. A strong surface temperature inversion causes the synoptic winds to decouple from the surface and to flow over the top of the inversion at accelerated speeds. Within the inversion wind speed decreases and may become very light or even calm but quite frequently winds speeds can be greater than 11km/h.

It is not uncommon for wind speeds within inversions to be quite strong. For example, in Australia winds in excess of 20km/h have been recorded when a surface inversion existed. These higher wind speeds are likely when inversion strength is not sufficient to cause complete decoupling of synoptic winds from the surface.

Key elements of weather associated with a surface temperature inversion are:

- a significant drop in wind speed as sunset approaches, which signals the beginning of synoptic wind decoupling;
- drainage winds flowing down slope and around obstacles at directions and speeds dictated by topographic features rather than the overriding general weather pattern; and
- a fog and frost.

While the inversion is eroding (usually early morning), rebalancing of decoupled winds to the surface and inversion wind decay can cause gusty winds of variable direction at speeds stronger than expected of the synoptic situation.

THE HAZARDS OF A SURFACE TEMPERATURE INVERSION

Weak inversions are unlikely to be hazardous to spraying but strong inversions can be very hazardous. When strong inversions occur the atmosphere is very stable dynamically (page 8) and:

- winds tend to be laminar (not turbulent), leading to stagnant and very low rates of dispersion;
- airborne droplets, vapours and particulates can remain at quite high concentrations for a number of hours and drift long distance, sometimes fanning out to cause widespread damage (see image page 24);
- the direction and distance of pesticides movement is very hard to predict;
- the movement of drift will vary depending on the landscape;
- droplets or their remnants can move next to the surface and concentrate in low-lying areas or float just above the surface for long distances (tens of kilometres) (Figure 25); and
- management can be difficult due to the great variability of inversion occurrence, intensity and hazard level between dusk and dawn. The variability is mainly caused by transient cloud intermittently limiting radiative cooling, surging of drainage wind flow and downward turbulent bursts.

WHEN AND WHY DOES A SURFACE TEMPERATURE INVERSION OCCUR?

Surface inversions can occur at any time of the day or night but those occurring between dusk and early morning are most relevant to pesticide application. Such inversions are most commonly generated by surface radiative cooling and secondly by cold air advection – that is, cold air flows into an area and undercuts warm air.

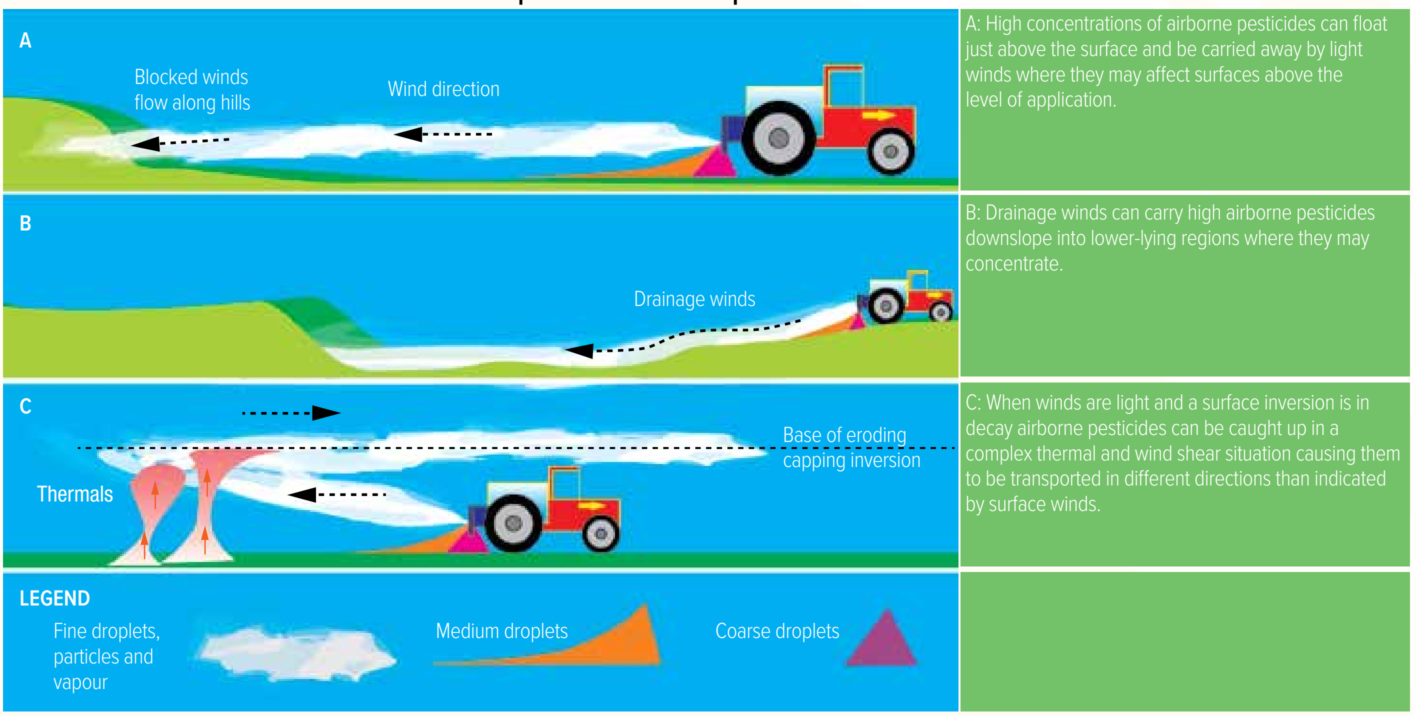
1. Radiation surface inversion

There is a common misconception that radiation inversions only form when wind speeds are less than 3km/h and skies are clear. Such conditions are simply the most ideal conditions for radiation inversions to form. Australian research by the GRDC shows it is quite common for inversions to exist when wind speeds are in excess of 15km/h and skies are fully overcast.

Light winds and clear sky conditions certainly lead to early and rapid onset of inversion conditions which may form before sunset.

A surface temperature inversion formed by radiation cooling is often accompanied by a significant drop in wind speed in the evening. The drop is caused by the synoptic wind decoupling from the surface. However, as winds within the inversion 'dome' begin to flow off slopes, wind speeds are found to often increase after the initial drop in speed.

FIGURE 25 Possible movement of airborne droplets in surface temperature inversion conditions.



SOURCE: GRAEME TEPPER

Radiation inversions begin to form when heat radiating back into the atmosphere causes the ground to cool. In turn, the air in contact with the ground becomes cooler than the air above. This generates the surface temperature inversion condition of a layer of air being cooler at the surface. Some soils retain heat after sunset and only cool slowly. The retention of heat, especially over sparsely vegetated ground, can delay inversion formation.

An inversion can occur within 20cm of the soil surface but not actually reach the surface due to very small-scale thermals driven by the warm earth. This situation is most likely in the early evening in calm conditions. While not well documented or understood, pesticides could become concentrated and drift in this low-level inversion, especially if vegetation cover is sparse.

Radiation inversions are the most dangerous for spraying operations as they cause airborne droplets, vapours and particles to remain concentrated at a low level for long periods. Winds within the inversion can carry airborne pesticides long distances.

2. Advection inversion

Cold air drainage off gentle slopes and sea breezes surging far inland late at night can seriously affect spray operations. Both advect dense cool air into a region to initiate or strengthen an inversion. Both can also cause subtle wind shifts that need to be factored into management decisions. Often, local knowledge and keen observation will be the only means an applicator has of detecting and managing the wind shifts.

TRANSPORT OF AIRBORNE PESTICIDES WITHIN A SURFACE TEMPERATURE INVERSION

To understand the transport of airborne pesticides within a strong surface temperature inversion, a distinction needs to be made between surface temperature inversions forming over flat terrain and those occurring over slopes.

Over flat terrain a surface temperature inversion forms when air in contact with the ground is cooled by terrestrial radiation. The inversion gradually intensifies and deepens as the surface cools. Air within the radiation inversion does not tend to flow out of the region, but remains in place. Thus, airborne pesticides tend to float over the immediate area of application unless local winds develop to carry them away.

Over gentle sloping terrain a surface temperature inversion also forms when air in contact with the ground is cooled by terrestrial radiation. The cooled layer remains quite shallow over the slope and is typically only 2 to 10m deep because gravity continually pulls it downward, causing drainage winds.

Drainage winds occur when temperature inversions exist on slopes. Drainage winds moving cool air off-slope and into low-lying regions may initiate a surface inversion or intensify an existing one over flat terrain beyond the slope. Thus, drainage winds can transport airborne pesticides at high concentrations for long distances, downhill and also into low-lying regions and valleys (Figure 25, B).

INVERSION LIFECYCLE

The development and structure of an inversion is rarely simple (Figure 27). The timing and structure can vary a lot, with variations often significantly impacting spray operators. Therefore it is advisable to constantly monitor spraying conditions from dusk to an hour or so after sunrise.

Variations of inversion life cycle occur in response to many factors, including influences of topography and surface roughness, rates of cooling, wind, turbulent mixing, 'blanketing' effects of transient cloud and cold-air drainage winds intermittently injecting air into the base of the inversion.

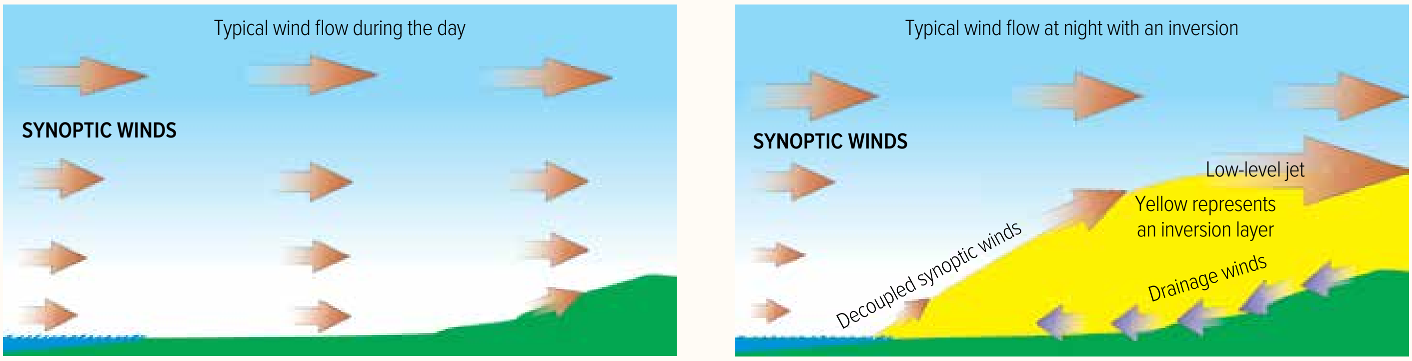
On most nights, at least a weak surface temperature inversion will form even under overcast skies unless winds exceed about 15km/h. Note that inversions have been detected with much stronger winds. Rain showers may interrupt inversion occurrence but do not preclude occurrence before or after a shower.

Very strong inversions, most hazardous to spray operations, typically occur between dusk and sunrise when winds are less than about 11km/h and skies are clear or clouds have clear gaps between them – it is not heavily overcast.

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 27 and 28), while the higher levels of the inversion remain intact as a 'capping inversion' until the thermals and/or turbulence completely destroys the inversion.

While the capping inversion exists (Figures 27 and 28) the potential for a blanket of concentrated pesticide to drift many kilometres is extremely high. If conditions at the end of the decay are unstable, pesticide may rise and diffuse into the atmosphere; if they are neutral, the pesticide will finally settle.

FIGURE 26 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).



SOURCE: GRAEME TEPPER

FIGURE 27 An idealised development and decay of a surface temperature inversion with no wind and clear skies. The vertical temperature profile is depicted by the red/blue line.

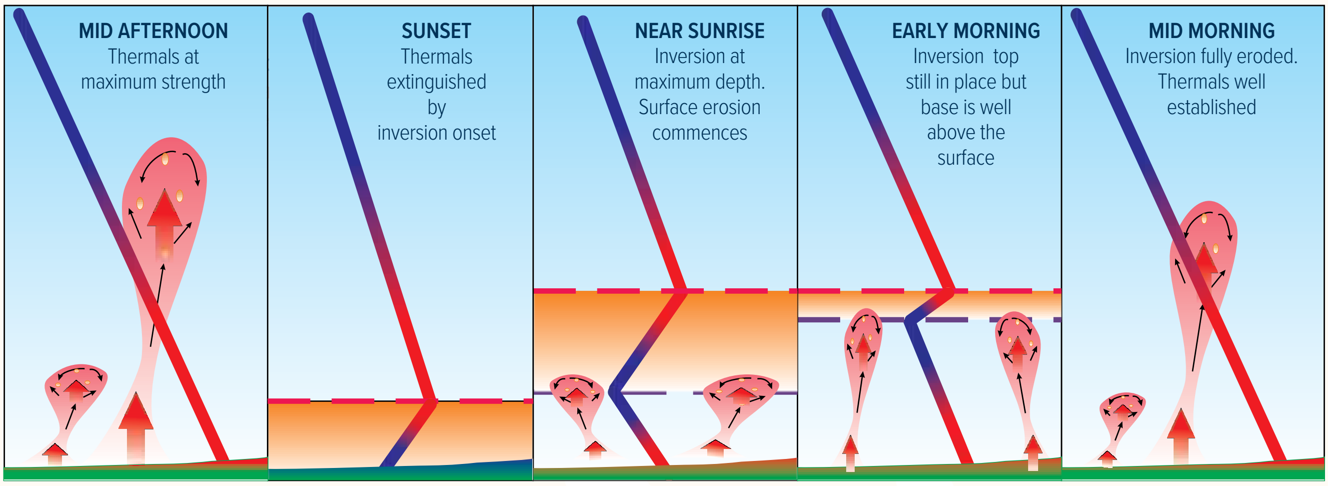


FIGURE 28 Pesticide particles can accumulate in the atmosphere for several days before being deposited on the surface.

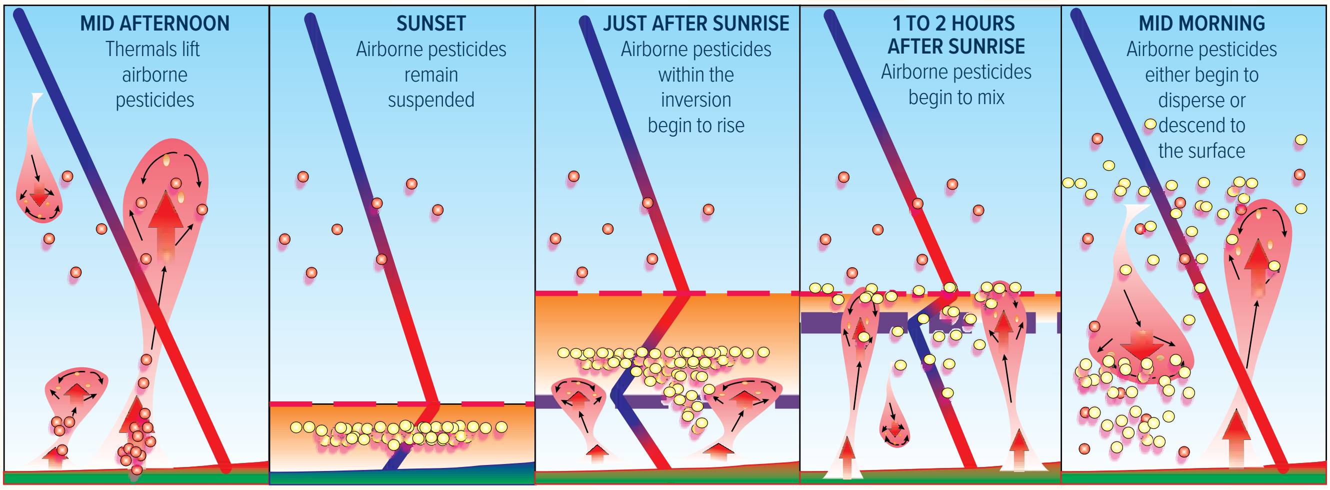


Figure 28 depicts a summer-time fine weather situation where thermals have lofted particles into suspension well above the surface. Spraying at night when an inversion exists caused particles to be suspended near the surface. The period of transition between the night-time inversion and the next day's 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

Note: Figure 27 depicts an idealised 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.

It is advisable to constantly monitor environmental conditions, especially from dusk to an hour or so after sunrise, to detect subtle changes that can alert to very hazardous spray conditions.

ACCUMULATION OF PESTICIDE RESIDUES IN THE ATMOSPHERE

If conditions are considered appropriate for spraying, the likelihood is that many applicators will be working in a region. Consequently, spray droplets from multiple sources could be carried into the atmosphere (Figure 28). 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 bought back to the surface.

RECOGNISING A SURFACE TEMPERATURE INVERSION

While it is reasonable to expect surface temperature inversions on most nights from dusk up to an hour or so after sunrise, forecasting and even observing the exact onset*, overnight variations and cessation times is not simple. The difficulty arises because of several factors, including periodic influence of transient cloud, synoptic and local wind flows and intermittent turbulence, which can critically affect the temperature difference between surface temperature and that of the air above. These variations may cause the inversions to form up to an hour before sunset or many hours after sunset. During the night the inversion intensity will vary. Cessation may be many hours before sunrise or up to an hour-and-a-half after sunrise.

The most common scientific method for detecting a surface temperature inversion requires the accurate measurement of the vertical temperature profile. On-farm, this is usually not practical (see page 24), so most spray applicators must rely on visual and other clues – basically relying on guesswork.

***As a general guide based on late afternoon conditions, when skies are clear and winds are calm inversion onset can be expected up to an hour before sunset. Onset time can be well after sunset if skies are cloudy and/or winds are strong.**

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: TERRESA ABERKANE (NZ)

Visual clues

Surface inversions may exist without visual indicators, but some visual indicators are:

- flags, trees or crops indicate light winds;
- mist, fog, dew or a frost;
- smoke or dust hanging in the air near to the surface; and
- cumulus clouds that have built up during the day collapse towards evening.

Other clues

A strong surface temperature inversion with very stable conditions is likely to be present if:

- wind speed is constantly less than 11km/h in the evening and overnight (be mindful that moderately strong and weak inversions can exist when winds are well in excess of 11km/h);
- cool, off-slope or contour flow breezes develop;
- distant sounds become clearer and easier to hear; and
- aromas become more distinct in the evening.

A strong surface inversion is unlikely to exist if:

- there is continuous low and heavy cloud;
- there is drizzle or rain
- wind speed is greater than 11km/h between sunset and sunrise;
- cumulus clouds exist.

GUESSWORK – NOT THE BEST DECISION METHOD

Applicators currently rely on basic clues to best guess if an inversion exists, having no way to determine if an inversion is strong or not. Guessing undoubtedly leads to false identification and missed events of inversions and poor discrimination of inversion hazard that ultimately must lead to many hours of lost opportunities to spray or inappropriate applications that can lead to widespread damaging drift.

Research that is taking the guesswork out of inversion hazard assessment

The GRDC had previously funded research 'On the relationship between inversions, stable conditions and easily observed quantities' and 'Management of spray drift through inversion risk awareness' (funded by the GRDC and managed by DAFWA). Current research, 'Air inversion modelling to manage spray drift' is funded by the GRDC.

Methods to take the guesswork out of determining inversions and the degree of hazard have been developed. These include automatic detection systems, which have the potential to provide real-time advice to operators and a means of verifying forecasts and forecast value. The degree to which the forecast helps growers realise some incremental economic and/or other benefit can be determined. The methods are yet to be proven to apply to all agroecological regions, which is an important step to establishing nationally applicable resources.

PRECAUTIONS FOR NIGHT SPRAYING

It is not always mandatory to stop spraying when a surface temperature inversion exists. However, operators must always aim to avoid spray drift and follow label requirements.

Guidelines for night spraying

1. CRITICAL – select spray quality and spray practices to eliminate all 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 (Figure 23, page 18).
6. Use wind meters, flags or smoke devices for wind flow and stability reference.

***1.5 hours is suggested as 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.**

Demons of night spraying

- Small droplets.
- Vapours and particulates.
- Inversion trapping and concentration.
- Drainage and other local winds.
- Variable wind speed and direction.

TEMPERATURE INVERSION DETECTION BY INSTRUMENTATION

To avoid under or over detection consider the following:

1. Temperature sensors must be absolutely reliable and accurate to at least 0.05 degrees for a 10m separation of sensors – most sensors are only 'accurate' to 0.1 degrees.
2. Sensors must read exactly the same – they rarely do – leading to compounding errors.
3. Radiation shields of good quality must be used to protect sensors. This is particularly important at low sun angles when the atmosphere is in transition between inversion and non-inversion conditions.
4. Constant monitoring of temperature difference is required since inversion occurrence, intensity and level of hazard can fluctuate quite rapidly throughout the night.
5. The detection of an inversion will not of itself alert to hazardous spray conditions.

NOTE: Accurate temperature difference simply determines a static stability. In meteorological and air pollution context, the dispersive nature of the air flow – whether it is smooth or turbulent (non-dispersive or dispersive) and suitable for spraying – is dependent upon the dynamic stability, not on static stability (page 8).

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6. Recording meteorological conditions

Before a spray application and just after spray application it is mandatory to record: wind speed and direction; temperature; relative humidity; and/or Delta T. Any significant changes occurring during the application should be noted. More frequent recording would be preferable especially for applications taking more than a few hours. A convenient time to record would be at every tank refill.

Readings should be taken at the pesticide release height and as close as possible to the site of application. For application in orchards and vineyards the records should be conducted outside the canopy on the upwind side.

Automated continuous recording representative of the spray environment would be advantageous. Onboard GPS-based weather stations provide the closest to continuously recording the conditions representative of the spray environment. However, although onboard instruments have high accuracy in their own right, some caution needs to be exercised when translating tractor-mounted recording to the environment at the release height.

RECORDING

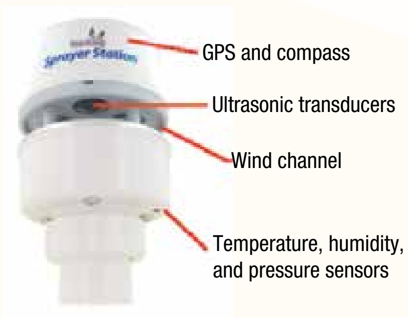
Wind

Record the average speed and direction over a period of at least a few minutes at the height of pesticide release.

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.

PHOTO: GRAEME TEPPER



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.

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

Small variations in atmospheric stability, wind, temperature and humidity can significantly affect spray operations. To effectively monitor them requires more than a casual glance at a forecast and taking a single observation. It requires applicators to be alert to the potential for change and an ability to monitor ongoing variations.

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.

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.

Useful resources

Bureau of Meteorology

Interactive maps (www.bom.gov.au/australia/charts/viewer) – these display numerous elements of interest to spray applicators down to regional level. These Numerical Weather Prediction (NWP) maps are used to guide the Bureau of Meteorology (BoM) official forecasts. The maps are produced from computer models. As they contain no input from weather forecasters, they do not include any symbols, such as cold fronts.

Four-day forecast maps (www.bom.gov.au/australia/charts/4day_col.shtml) – these may differ from interactive maps as they are manipulated by forecasters after consideration of additional data. For weather maps generated by forecasters, view the BoM official weather maps for the next four days.

Water and the Land (www.bom.gov.au/watl) – the BoM's Water and the Land website aims to provide an integrated suite of information for people involved in primary production, natural resource management, industry, trade and commerce.

Aviation Weather Services (www.bom.gov.au/aviation) – although designed for aviators this site has extremely detailed wind information.

SprayWise Decisions (www.spraywisedecisions.com.au) – an initiative of Nufarm, this innovative online service helps rural landholders and contractors to better plan and match the timing of agrochemical sprays to prevailing local weather conditions.

Willyweather (www.willyweather.com.au) – one of the many weather websites, this one is quite popular with growers.

Agricast (www.syngenta.com.au) – a tailored weather forecast that includes spray recommendations.

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Notes

WEATHER ESSENTIALS FOR PESTICIDE APPLICATION

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