Surface Inversions for Australian Agricultural Regions

What are surface inversions?

Surface inversions are layers of the atmosphere at the earth's surface in which temperature increases with height. This is the inverse of the normal temperature decrease with height that occurs due to the decrease of pressure with height (Figure 1).

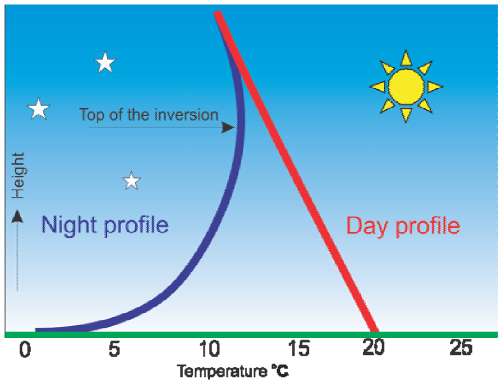

Figure 1 - Typical vertical profiles of temperature at night and during the day. The daytime temperature decreases with height. The night time temperature increases with height until it approaches the daytime profile and begins to cool with height. The top of the inversion is shown.

The Hazards of Surface Inversions

Surface inversions strongly suppress the dispersion of airborne pesticides (Figure 2) and the like. Thus, surface inversions can cause airborne pesticides to:

- remain at high concentrations for long periods over and close to the target,
- travel close to the surface for many kilometres in light breezes,
- move downslope and concentrate into low lying regions, and
- be transported often in unpredictable directions, particularly during the morning transition periods when airborne pesticides can be lifted above the surface and into the capping inversion.

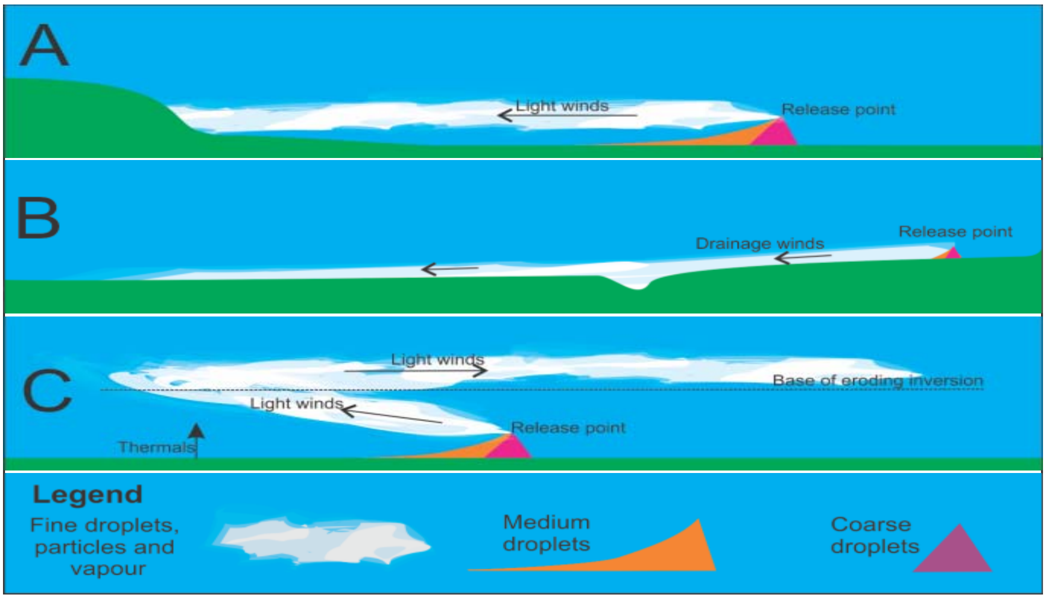

Figure 2 - Possible airborne pesticide concentration and transport within surface inversion conditions.

A: High concentrations of airborne pesticides float just above the surface. Light winds may transport the plume to non-targets.

B: Airborne pesticides can be caught up in drainage winds which carry them downslope and may concentrate them along slope and into lower lying regions.

C: Airborne pesticides caught up in a complex thermal and wind shear situation, particularly through the inversion decay period may be lifted into the capping inversion and be transported in completely different directions than indicated by surface winds.

Causes of surface inversions

Common causes of surface inversions are:

1. Advection of cool air: Surface inversions can form when cool air moves into and undercuts a warmer air mass. Such movement typically occurs with sea breezes and cold fronts. It may also occur when cool air drains downslopes and into warmer air at lower elevation.
2. Advection of warm air: Surface inversions occur when warm air flowing over cool surfaces has its lowest layers cooled more rapidly than those immediately above.
3. Shading by crops and forests can hold temperatures lower at the surface than immediately above.
4. Radiation cooling: Surface inversions usually begin to occur near sunset after the ground cools rapidly by losing heat energy through infrared radiation upward into space. That radiation passes through clear air with little effect. As the ground cools, the air in contact with the ground begins to cool directly by conduction leading to the lowest layer of air being cooler than higher layers. In shorthand, this is referred to as “radiation cooling”.

Radiation Inversions – the most hazardous

Inversions caused by radiation cooling – called ‘radiation inversions’- are the most hazardous to pesticide applications because they are the most likely to severely restrict dispersion and promote transport at high concentrations of the airborne pesticides.

Occurrence of Radiation Inversions

Radiation inversions occur most nights. Only when winds are strong enough to completely mix the lowest layers of the atmosphere and/or cloud cover severely restricts surface heating and cooling is there a chance that surface radiation inversions won’t form overnight.

Transport of airborne pesticides

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

1. **Radiation inversions over flat terrain** form 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.

2. **Radiation inversions over sloping terrain** also form 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 2m to 10 m deep because gravity continually pulls it downward; causing drainage winds. Drainage-wind advection of cool air away from the slope and over or into lower lying regions may initiate a ‘**drainage inversion’** or **intensify an existing radiation inversion**. Drainage inversions, once formed, have similar attributes to radiation inversions. Airborne pesticides can be transported long distances downhill, over flat terrain toward the lowest lying regions and into valleys by drainage winds.

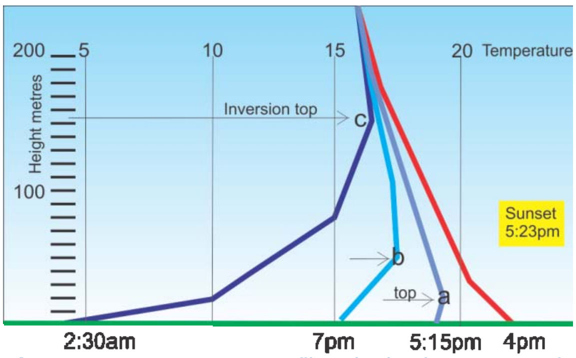

Figure 3 - Temperature profiles depict the onset and growth of a radiation inversion. An inversion is evident before sunset. The base of the inversion remains at the surface while the top gains height from a to b to c.

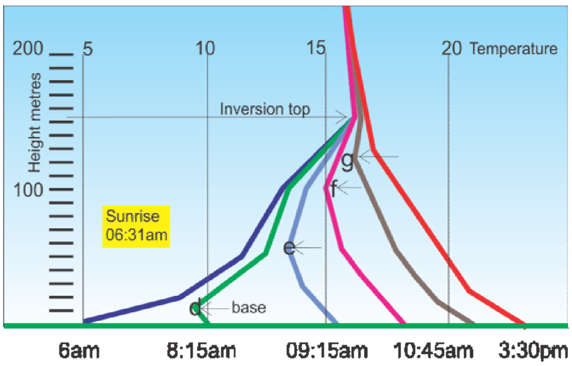

Figure 4 - Temperature profiles depicting the decay of the inversion. The top of the inversion remains constant at about 150 metres while the base progressively gains height; d, e, f to g. Shortly after 10:45am the inversion is completely eroded.

The Typical Lifecycle of Radiation Inversions

Initiation

Radiation and drainage inversions typically begin in the evening at about sunset as the ground surface cools and the air in contact with the surface loses sufficient heat by conduction to become colder than the air immediately above. With continued overnight cooling, inversions usually intensify and deepen up to the time of the overnight minimum temperature.

Cessation

Decay of radiation inversions typically begins just after sunrise as the sun begins to heat the surface. Ground surface heating begins to warm the air immediately above and erodes the inversion from the surface upward. The burning off process is aided by thermal currents lifting and mixing into the inversion layer.

The Remnant Capping inversion

The process of erosion from the surface upwards leaves the upper layers of the inversion intact for sometime after sunrise. The intact layers cap thermals that transport heat upward. During this period, airborne pesticides can be lofted into the cap by the thermal activity where they may concentrate before drifting long distances in directions that are possibly contrary to observed surface wind conditions.

Variations of Lifecycle

There are many variations to this idealised life cycle of radiation inversions. Onset may be delayed and overnight occurrence may be intermittent. Cessation may occur earlier than sunrise due to varying cloud cover, varying wind speed and intermittent turbulence.

Inversion Weather

An inversion can be likened to a dome of colder air next to the ground cut off and largely insulated from the surrounding atmosphere. Being isolated, the inversion weather can be significantly different from what might be expected from the broader weather patterns. Of significance:

- The inversion onset leads to the often-observed significant drop in wind speed as sunset approaches; signalling the decoupling of the general winds from the surface.
- Drainage winds can flow downslope and/or around obstacles with directions dictated by topographic features rather than the overriding general weather pattern.
- Inversions can lead to an anticlockwise (in the southern hemisphere) turning of night time winds.
- Inversions are prerequisites to fog and frost development.
- Inversion break up can be accompanied by winds stronger and gustier than the winds experienced throughout the day.

What Should Chemical Applicators Do to Anticipate and Recognise Radiation Inversions

It is essential that an applicator anticipate and recognize the radiation inversion potential and occurrence for any spray application made between sunset and an hour or so after sunrise.

While it is reasonable to expect surface inversions on most nights, it is not a simple task to forecast exactly the onset and cessation times of surface inversions. The difficulty arises because of the periodic influence of transient cloud cover, varying wind speeds, occurrence of intermittent turbulence and the varying potential of different surfaces to cool the air. See more guidance below.

Anticipation of an inversion

The potential for inversions to occur and to adversely hold high concentrations of airborne pesticides near the surface should always be anticipated between sunset and up to an hour or two after sunrise; unless one or more of the following conditions occur:

1. There is continuous overcast, low and heavy cloud.
2. There is continuous rain.
3. Wind speed remains above 11km/h for the whole period between sunset and sunrise. Be mindful that established inversions can sometimes still occur when winds are in excess of 11km/h (based on Pasquill Stability Classes 1961).

The occurrence of any of the three conditions does not wholly exclude surface inversion existence but they do indicate conditions not normally conducive to the drift of high concentrations of airborne pesticides.

NOTE: To assist applicators determine the likelihood of inversion conditions and to avoid them, it would be helpful if land owners developed climate data bases for target areas, with a focus on:

- The frequency of radiation inversions and intensity for the time of year and location, e.g. for many Australian locations the weakest inversions occur in winter – the most intense in late Spring and Summer.
- The frequency of drainage winds over the target fields in relation to different wind regimes.

Recognition of an inversion

The most reliable scientific method of detecting inversion conditions is to measure and determine if temperatures are warmer above the surface than at the surface. However, since applicators rarely have access to suitable instrumentation, simpler methods of inversion recognition must be employed.

Surface inversions may exist overnight without visual clues but some useful visual indicators are:

- Cumulus clouds that have built up during the day tend to collapse toward evening.
- Mist, fog, dew and frost occur.
- Smoke or dust hangs in the air and/or moves laterally in a concentrated package.

Other clues include:

- There is a large difference between the observed maximum temperature and the night-time temperature.
- Wind speed in the evening and overnight are considerably less than during the day.
- Cool off-slope breezes develop in the evening.
- The clarity of remotely generated sounds increases at night.
- Aromas become more distinct at night than during the day.

Reference
Pasquill, F. (1961). The estimation of the dispersion of windborne material, The Meteorological Magazine, vol 90, No. 1063, pp 33-49.