Frost Protection Principles

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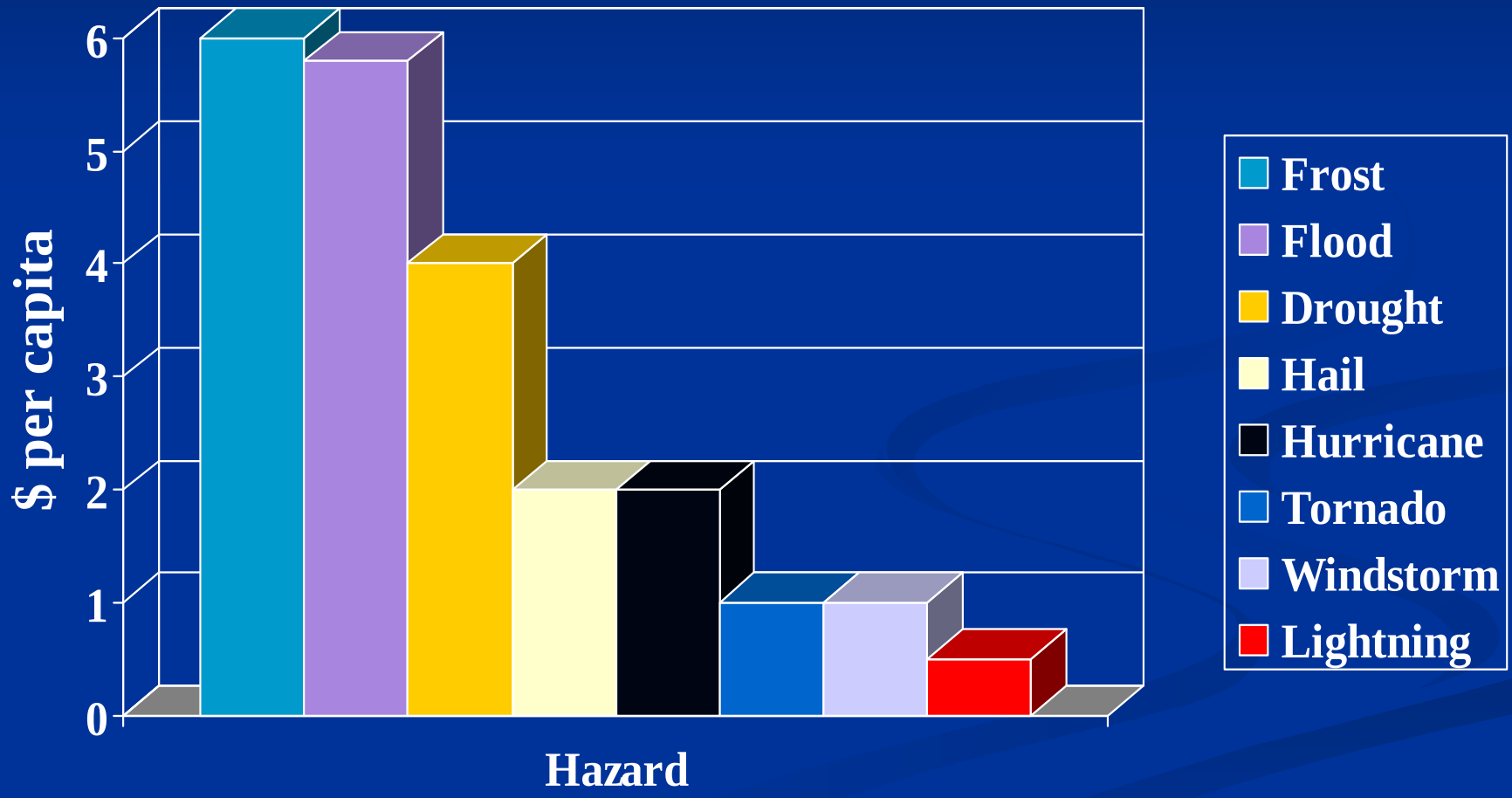
Agriculture & Natural Resources
Central Valley Region

Mean Annual Losses to Weather Hazards in the United States



First, a good orchard thermometer in a proper thermometer shelter is a must

Critical temperatures for damage ---

- **Vary with the stage of bloom.**

Green tip -- 25^{o} F

Popcorn -- 27^{o} F

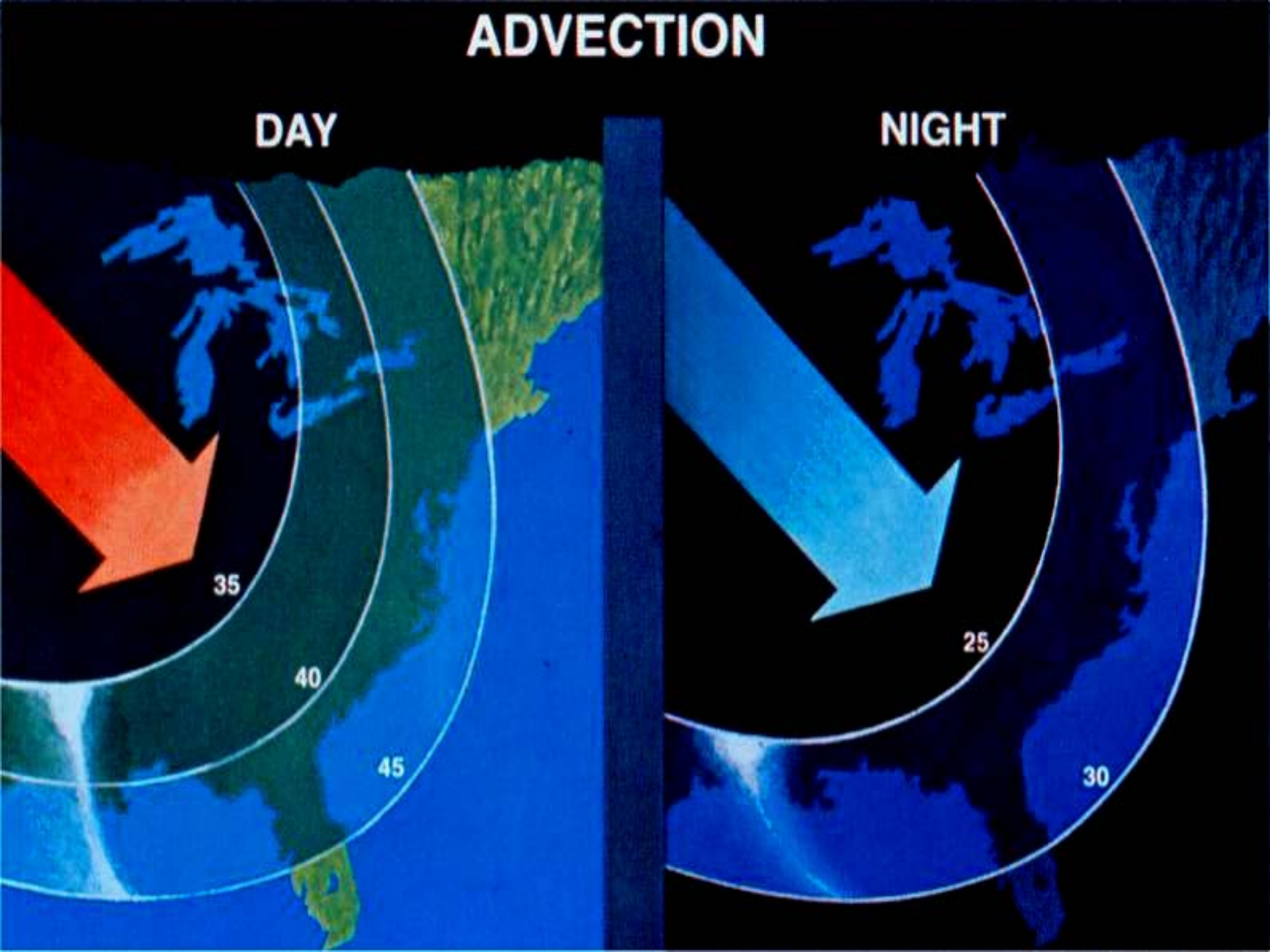
Full Bloom -- 28^{o} F

Frost damage at bloom, ovaries are killed and turn brown

Frost damage from a late spring freeze (April 9th) followed by nut drop

Frost damage from late spring freeze (April 20th). Fruit scarring, ovary killed, followed by fruit drop

Small green fruits – 30^{o} F


ADVECTION
DAY
NIGHT
35
40
45
25
30

Arctic air mass… advection freeze in December 1990

Radiation

Day

Night

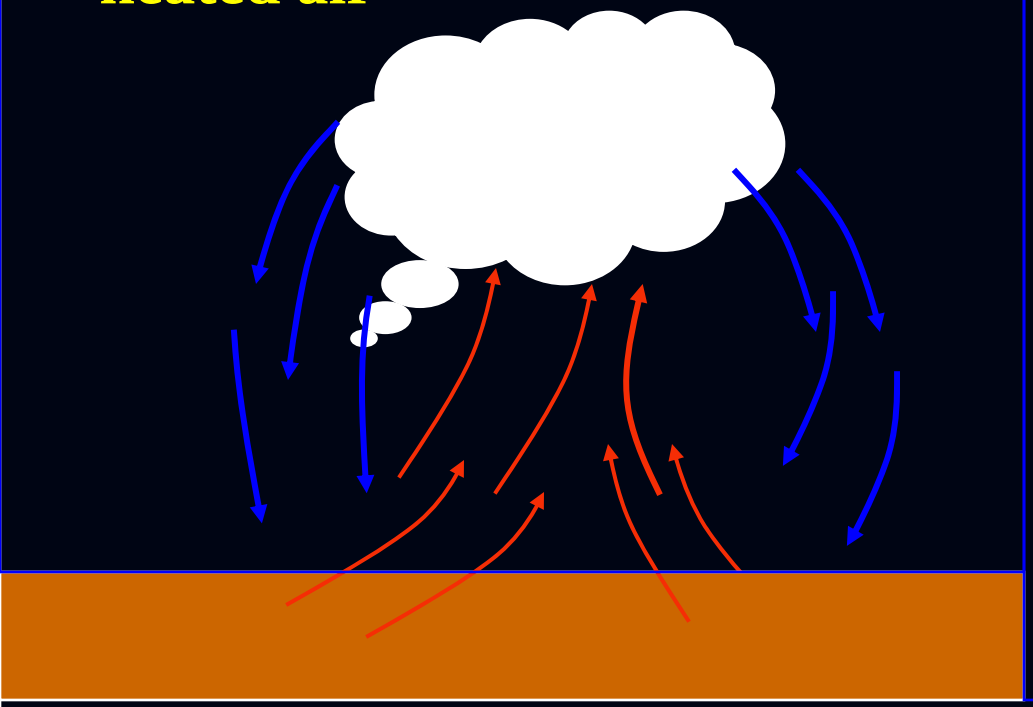
Methods of Heat Transfer

Conduction- from molecule to molecule

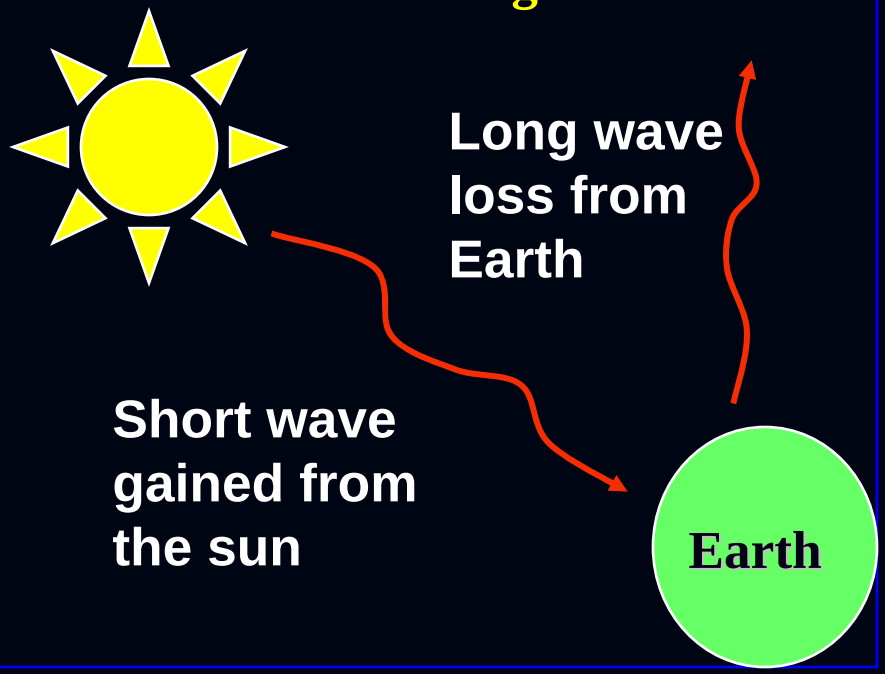
Heat Source

Metal bar

Convection - by movement of heated air



Radiation - energy passing from one object to another without a connecting medium



Properties of Water

- High Heat Capacity
- Most Dense at 39º F
- Contains Latent Heat

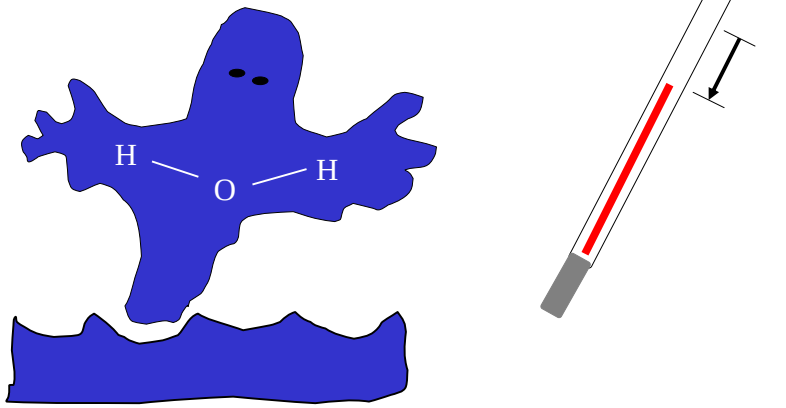
Latent Heat

- Heat Stored in Water
- Chemical Energy
- Hydrogen Bonds

Methods of Heat Transfer

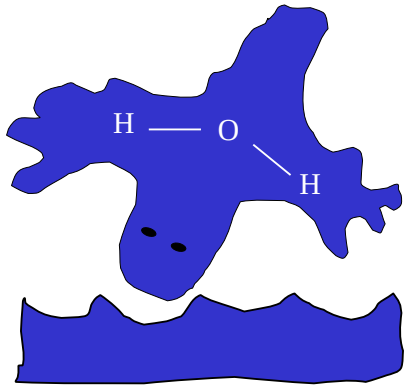
Latent Heat - Chemical Heat

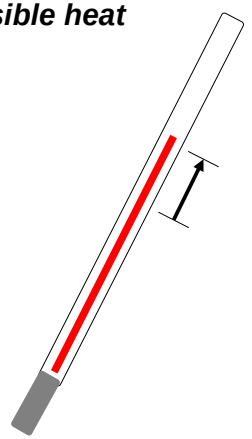
When water molecules evaporate, sensible heat is changed to latent heat and the temperature drops



Evaporation

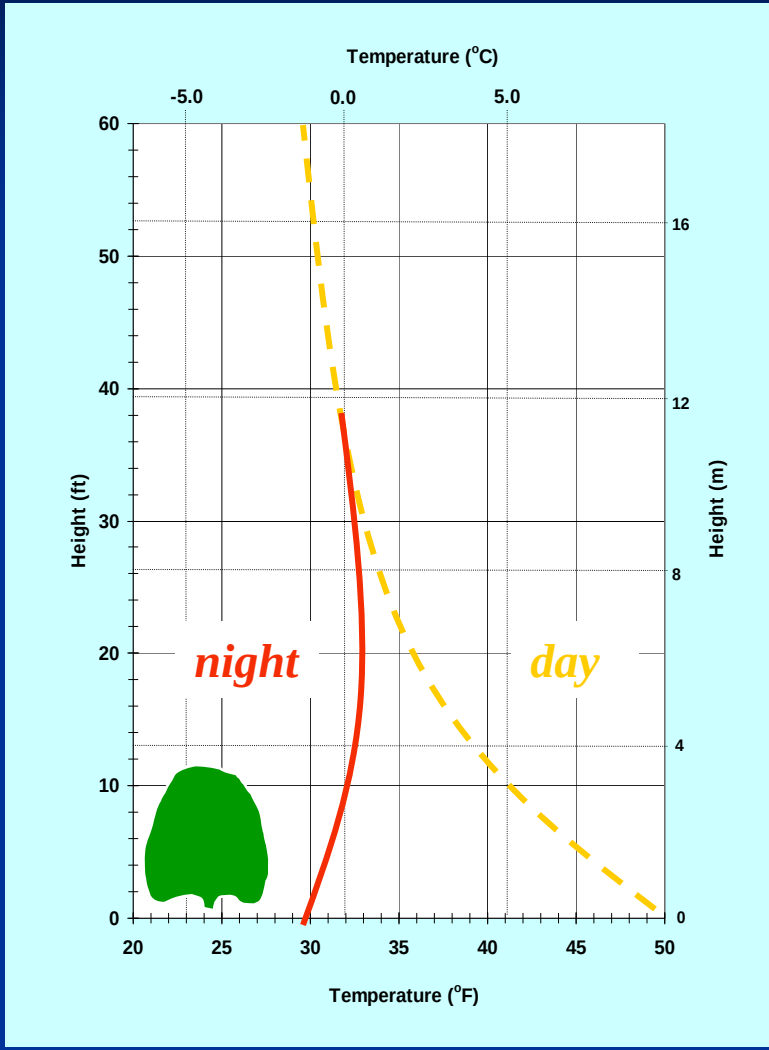
When water molecules condense, latent heat is changed to sensible heat and the temperature rises





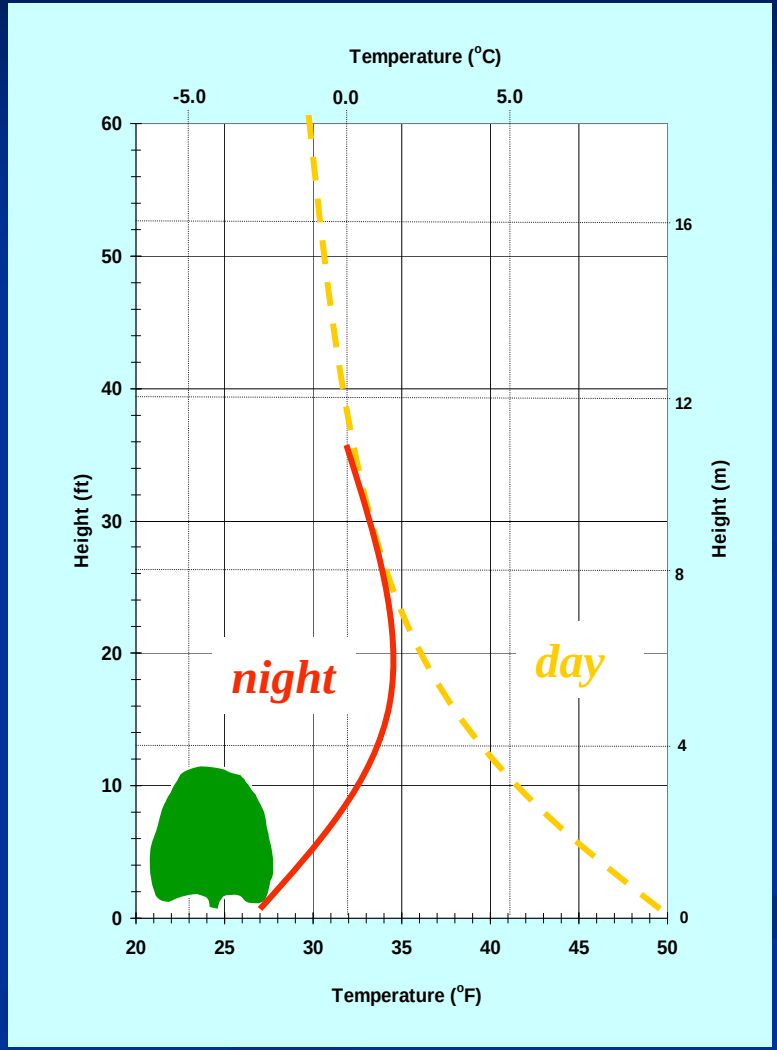
Condensation

High Humidity



Low Humidity

Colder at night !

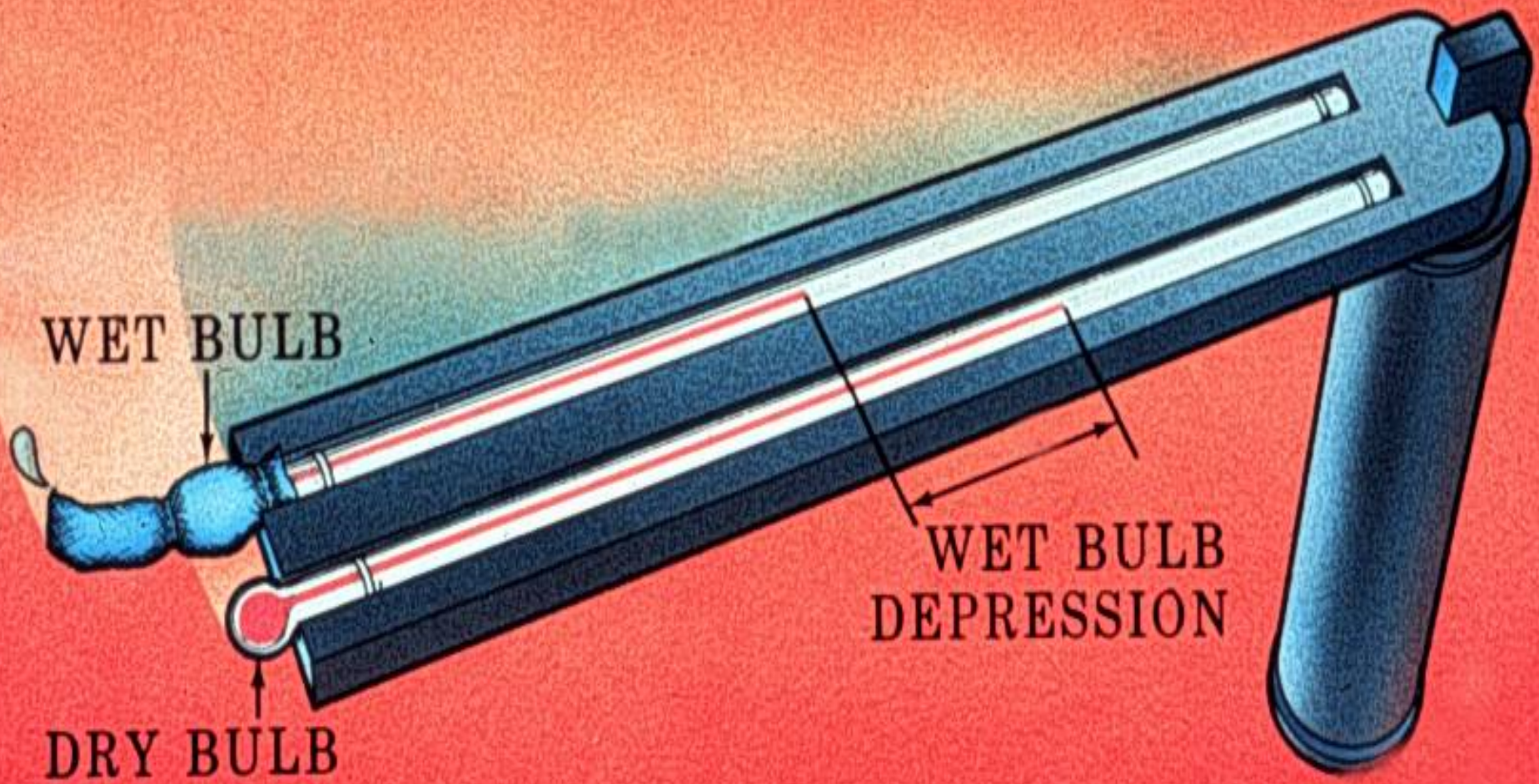


High humidity slows the decline of overnight temperatures

Water Vapor Concentration

- **The higher the concentration the higher the humidity**
- **When water vapor is saturated, a thermometer will read the wet-bulb temperature**
- **A wet plant's temperature cannot fall below the wet-bulb temperature**

SLING PSYCHROMETER METHOD OF MEASURING RELATIVE HUMIDITY



Dew Point

- **The dew point temperature is the temperature when relative humidity = 100 %**

- **When surface temperatures reach dew point, condensation (dew) forms releasing sensible heat which slows temperature drop**

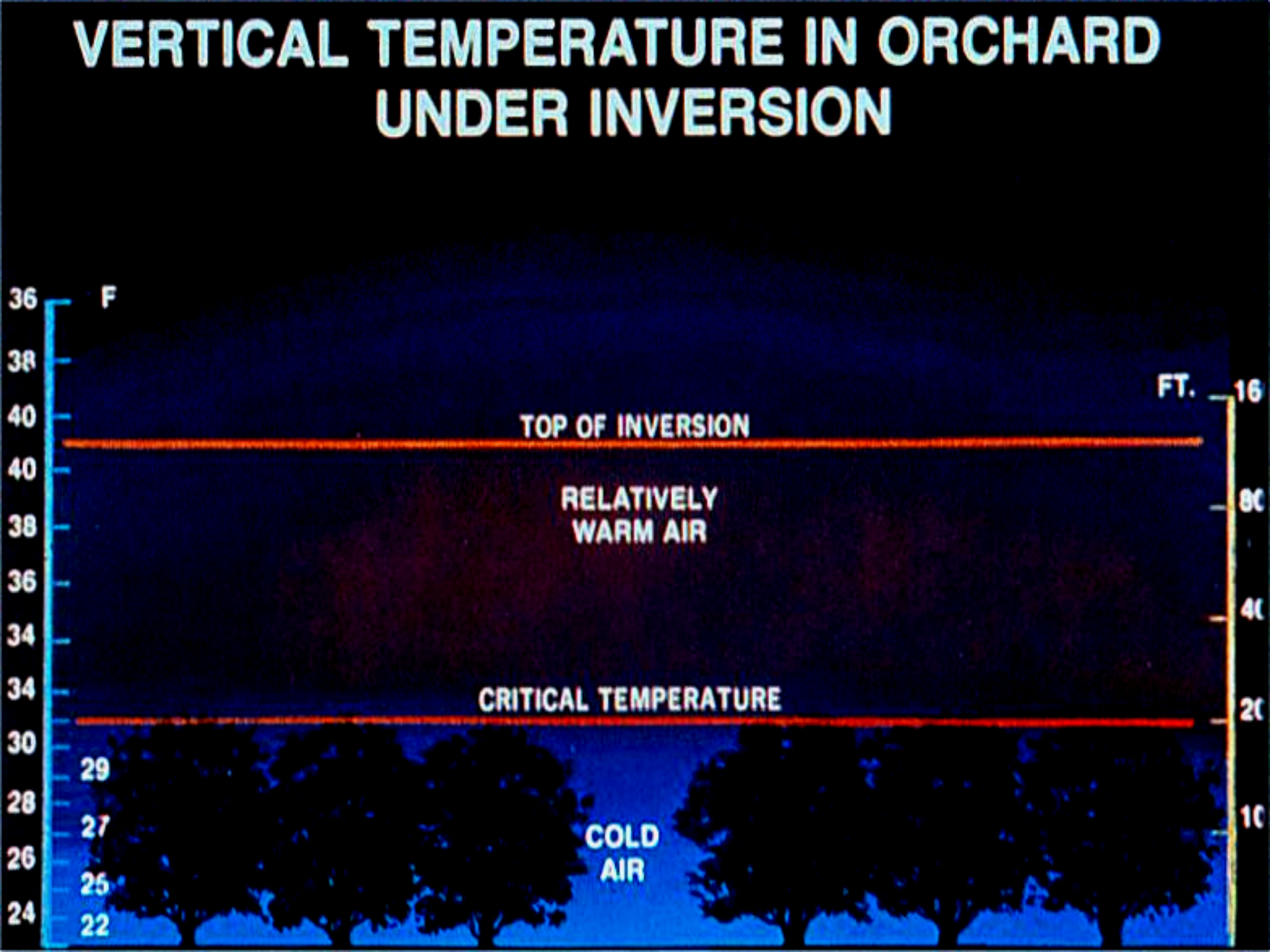
Dew point Temperature

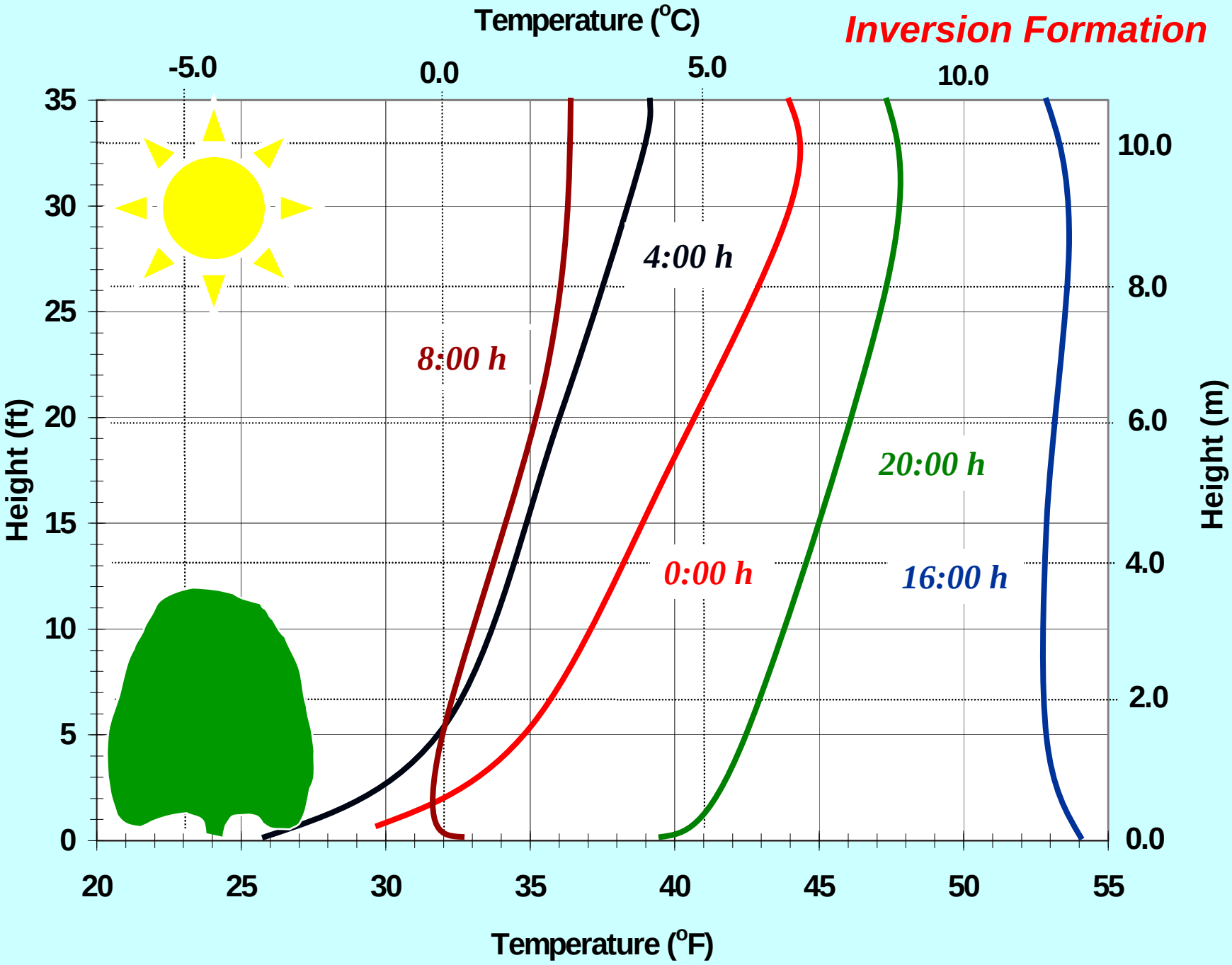
- ✓ Slowly add ice cubes to water in a shiny can to lower the can temperature
- ✓ Stir water with a thermometer while adding ice cubes to insure the same can and water temperature
- ✓ When condensation occurs on the outside, note the dew point temperature

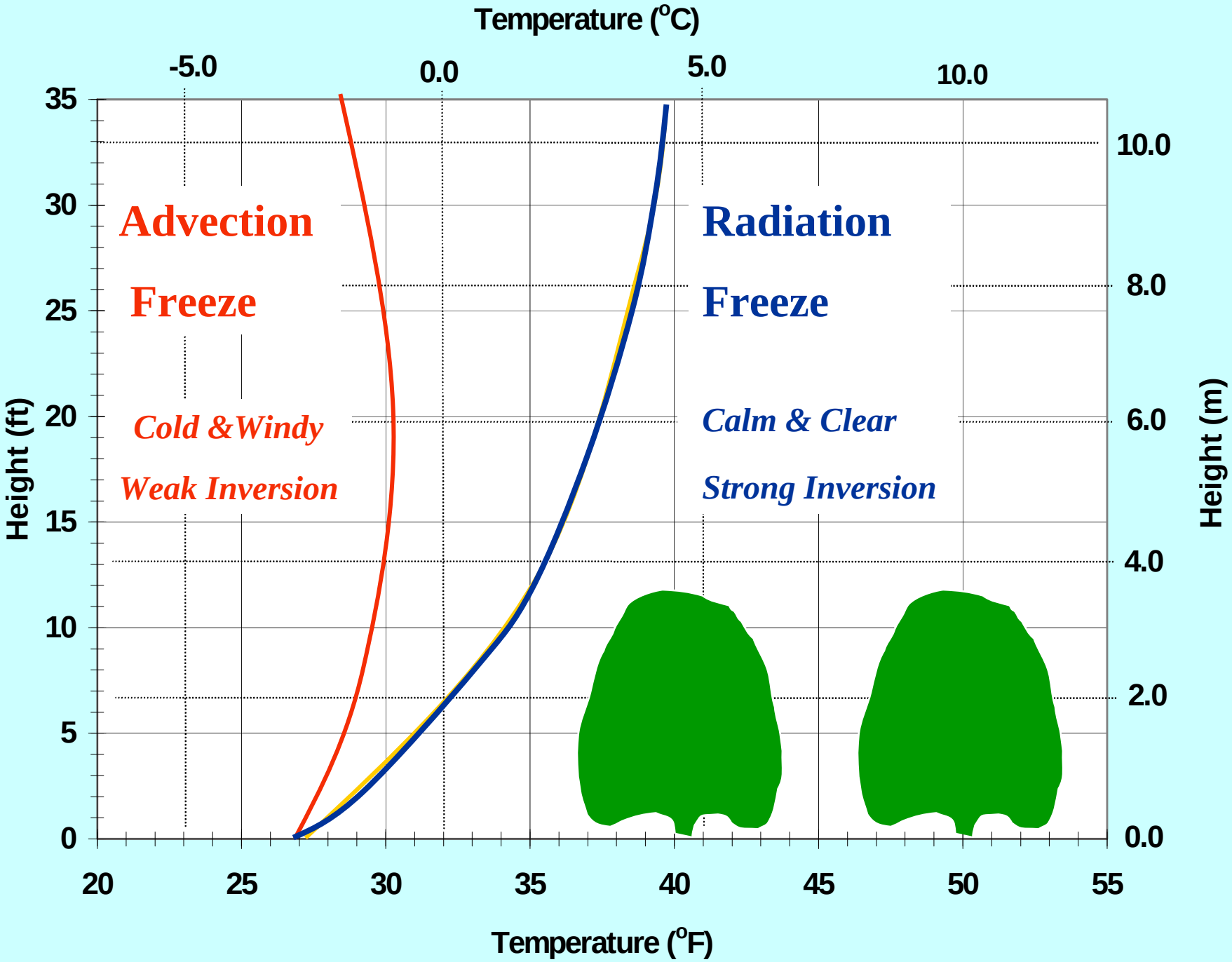
An inversion…

- **Occurs when temperature increases with height**
- **Forms when air near the ground cools more rapidly than the air above**
- **Is associated with radiation freezes**

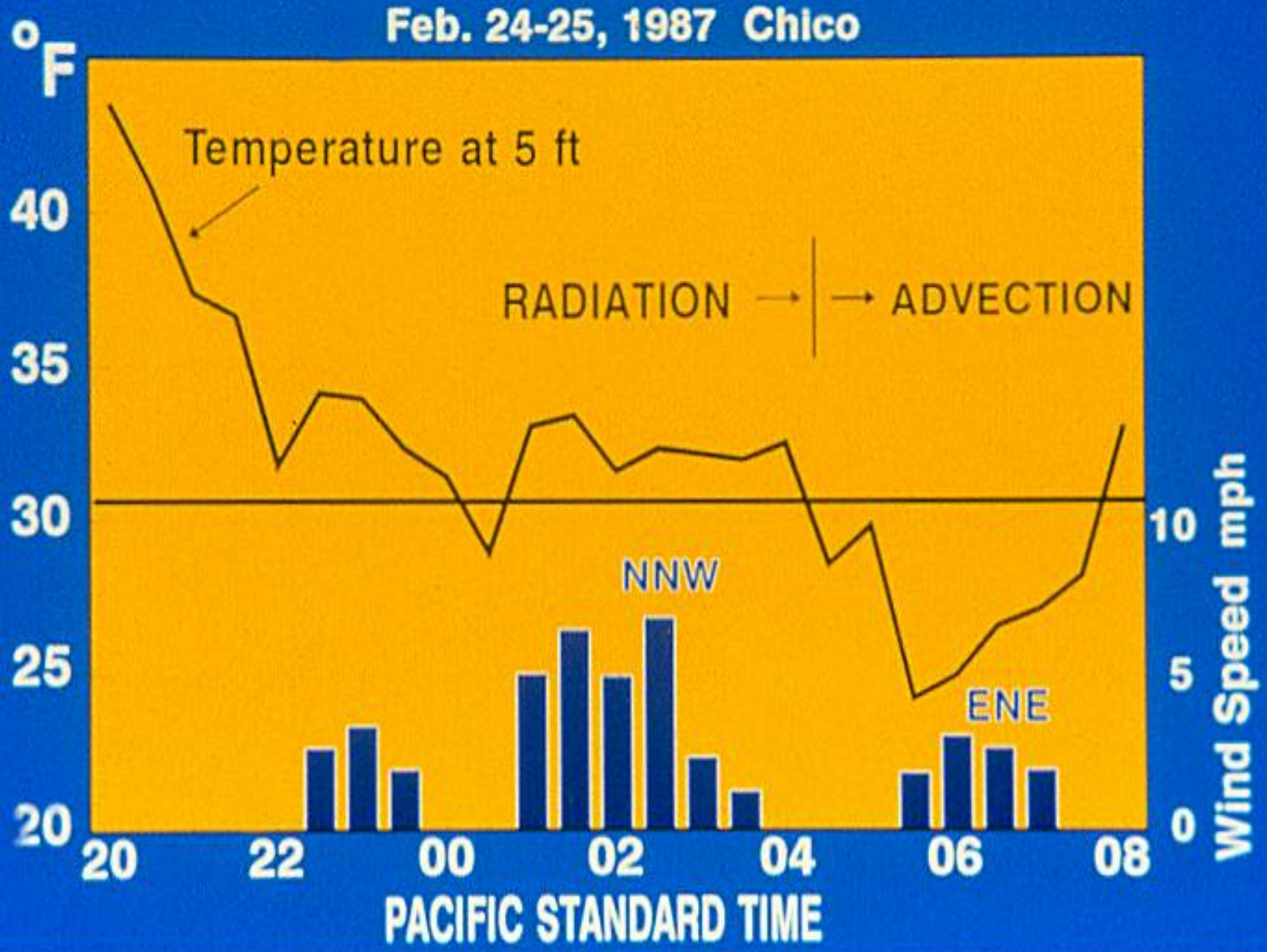
VERTICAL TEMPERATURE IN ORCHARD UNDER INVERSION




Inversion Formation
Temperature (°C)
-5.0
0.0
5.0
10.0
Height (ft)
35
30
25
20
15
10
5
0
Height (m)
10.0
8.0
6.0
4.0
2.0
0.0
8:00 h
4:00 h
0:00 h
20:00 h
16:00 h
20
25
30
35
40
45
50
55
Temperature (°F)


Temperature (°C)
-5.0
0.0
5.0
10.0
Advection
Freeze
Cold &Windy
Weak Inversion
Radiation
Freeze
Calm & Clear
Strong Inversion
Height (ft)
35
30
25
20
15
10
5
0
Height (m)
10.0
8.0
6.0
4.0
2.0
0.0
20
25
30
35
40
45
50
55
Temperature (°F)

RADIATION Vs ADVECTION FROST



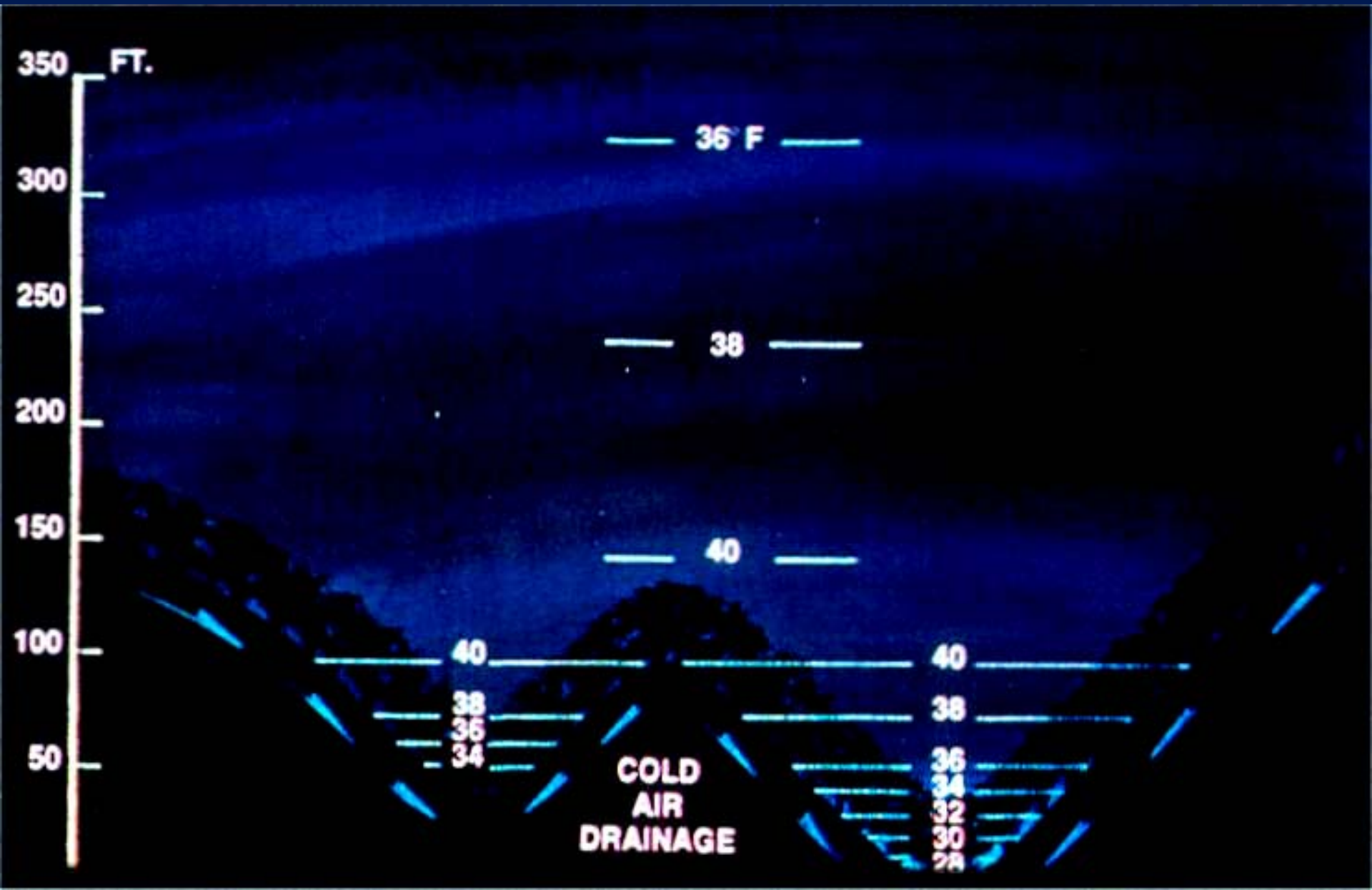
Passive Frost Protection Elements

- **Site Selection**
- **Ground Cover**
- **Soil Water Content**
- **Covers & Wraps**
- **Bacteria Control**

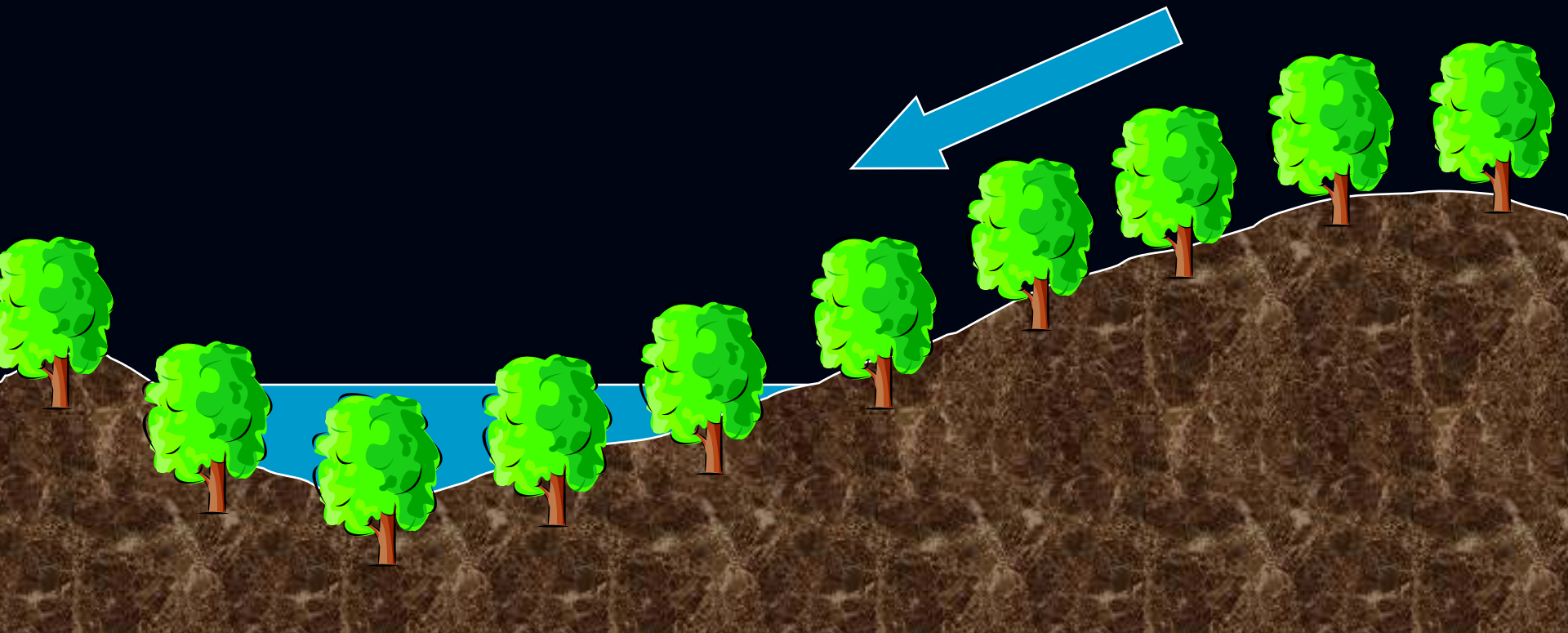
Cold Air Drainage

- **Cold air is heavier (more dense) than warm air**
- **It flows down hill like water**
- **Accumulates in low areas**

Cold Air Drainage



Cold air drains to low spots

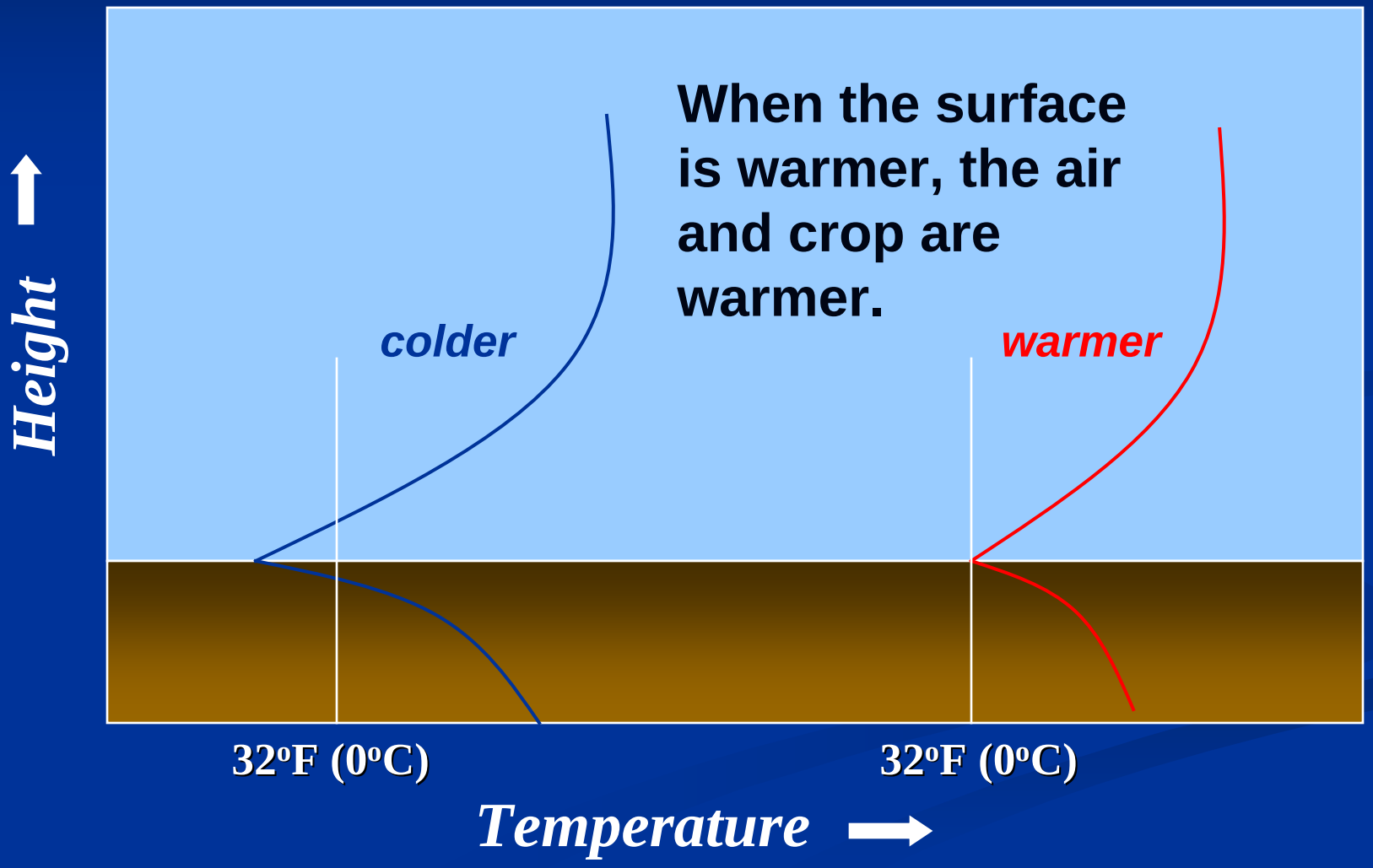


Freeze along Highway 65, Porterville, CA

Site Selection

- **An important management decision**
  - **Avoid low (cold) sites**
  - **Plant on North slopes to delay bloom**
  - **Air drainage from the site**
  - **Assess the risk of freeze damage**

Surface temperature affects the air and crop temperature



Ground covers….

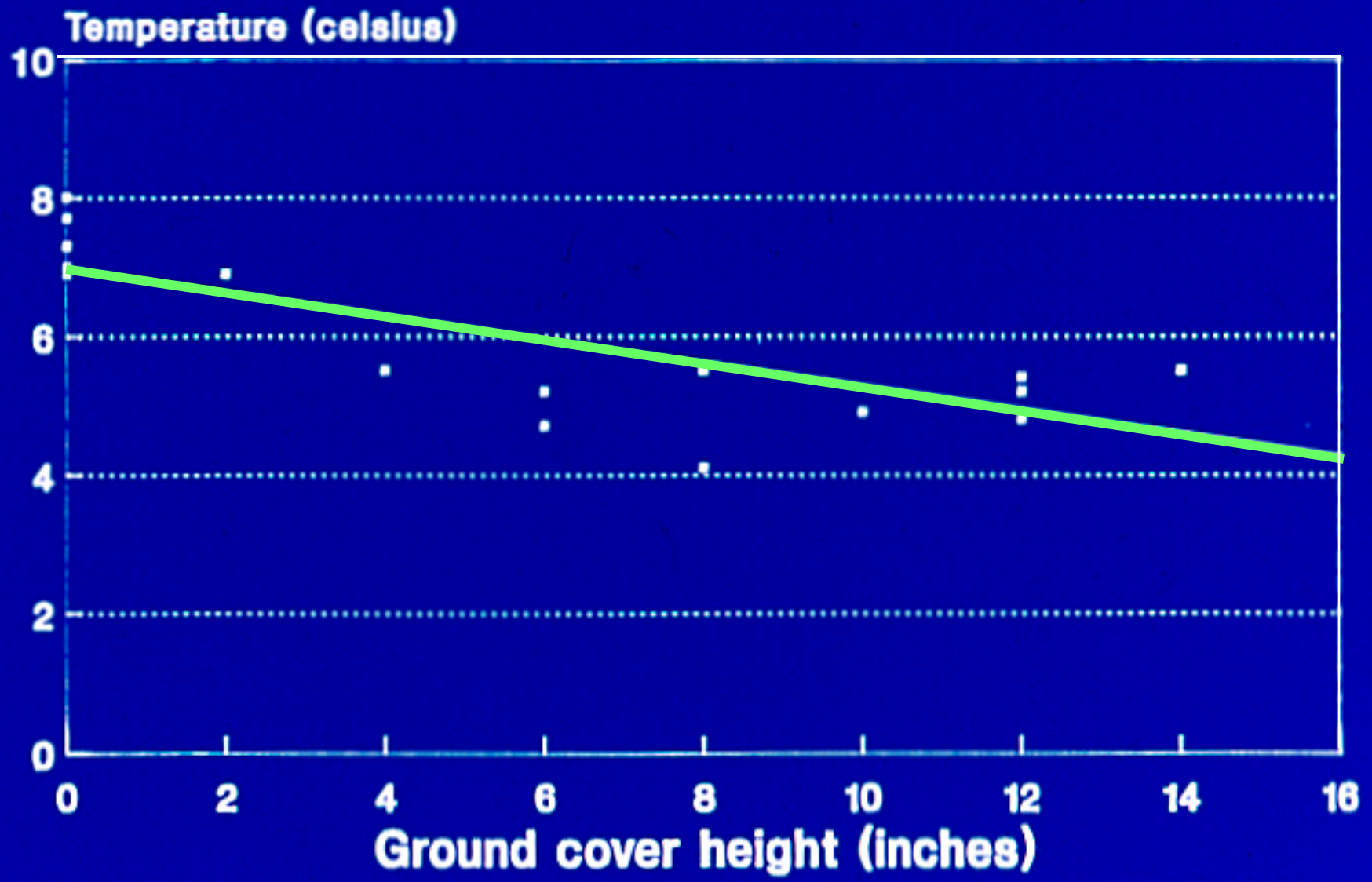
keep mowed short for the warmest orchard condition

Ground Covers

- Reflect sunlight
- Dry the soil & evaporate water
- Reduce soil heat conduction
- Result in colder minimum temperatures

Ground Cover Temperatures

March 22, 1989

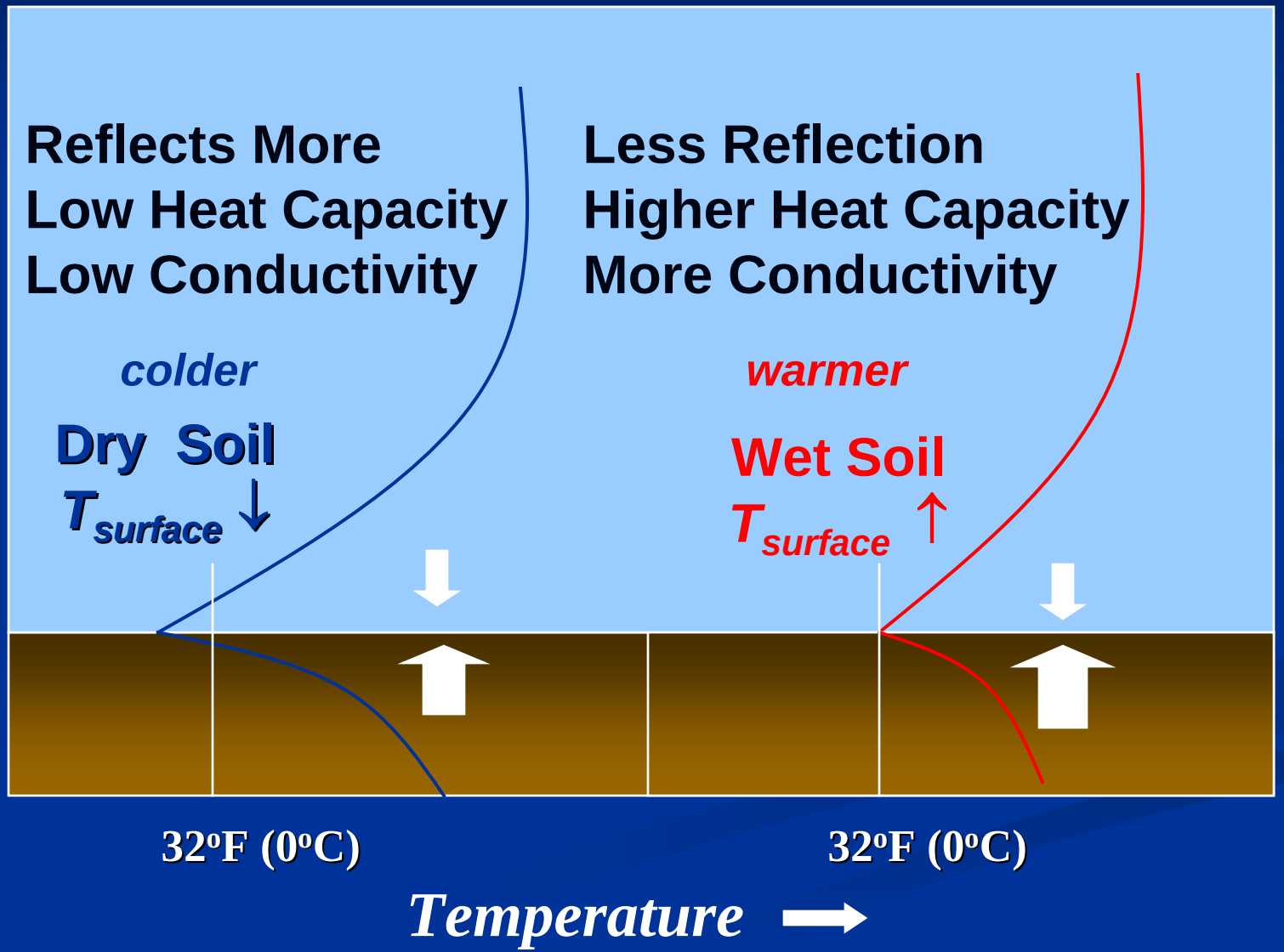


Loose, recently cultivated soil creates the coldest orchard floor condition

Ground Cover Summary

- **Fallow, bare firm moist soil is warmest**
- **Cut covers short with a mower or chemically mow**
- **Don’t cultivate**
- **Rewet dry soil**

Soil Water Content



Soil water

- Wet the top foot
- Wet the entire surface
- Be near field capacity
- Water 1-2 days ahead of a freeze to help store heat in the soil

Covers and wraps on young trees

Reduce:

- Radiation loss
- Convection loss

Management must:

- Keep insulation dry
- Cover all the way to the ground

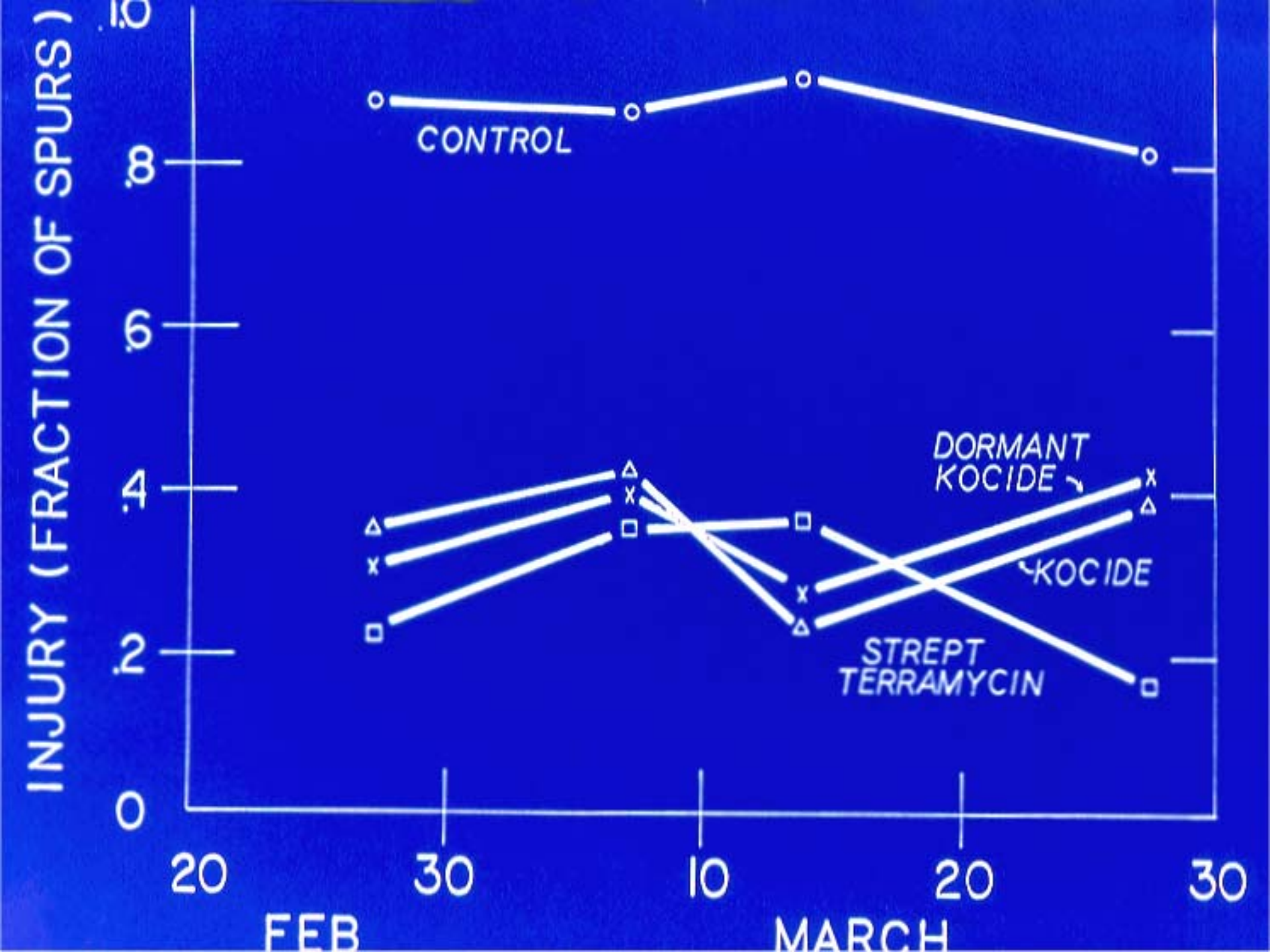
Freeze damage has been seen on tender, fall planted, containerized almond trees

Bacteria Control

- **Proteins in *Pseudomonas syringae* bacterial cell walls stimulate the formation of ice crystals.**
- **This is known as ice nucleation.**

Ice Nucleation

- **Water can supercool or freeze below the Melting Point (0ºC or 32ºF).**
- **In the temperature range for frost damage, bacteria cause 99% of ice nucleation.**


INJURY (FRACTION OF SPURS)
1.0
.8
.6
.4
.2
0
CONTROL
DORMANT
KOCIDE
KOCIDE
STREPT
TERRAMYCIN
20
30
10
20
30
FEB
MARCH

Ice Nucleation

- Kill the bacteria w/ copper
- Competitive bacteria
- Remove ground cover

Active Frost Protection methods

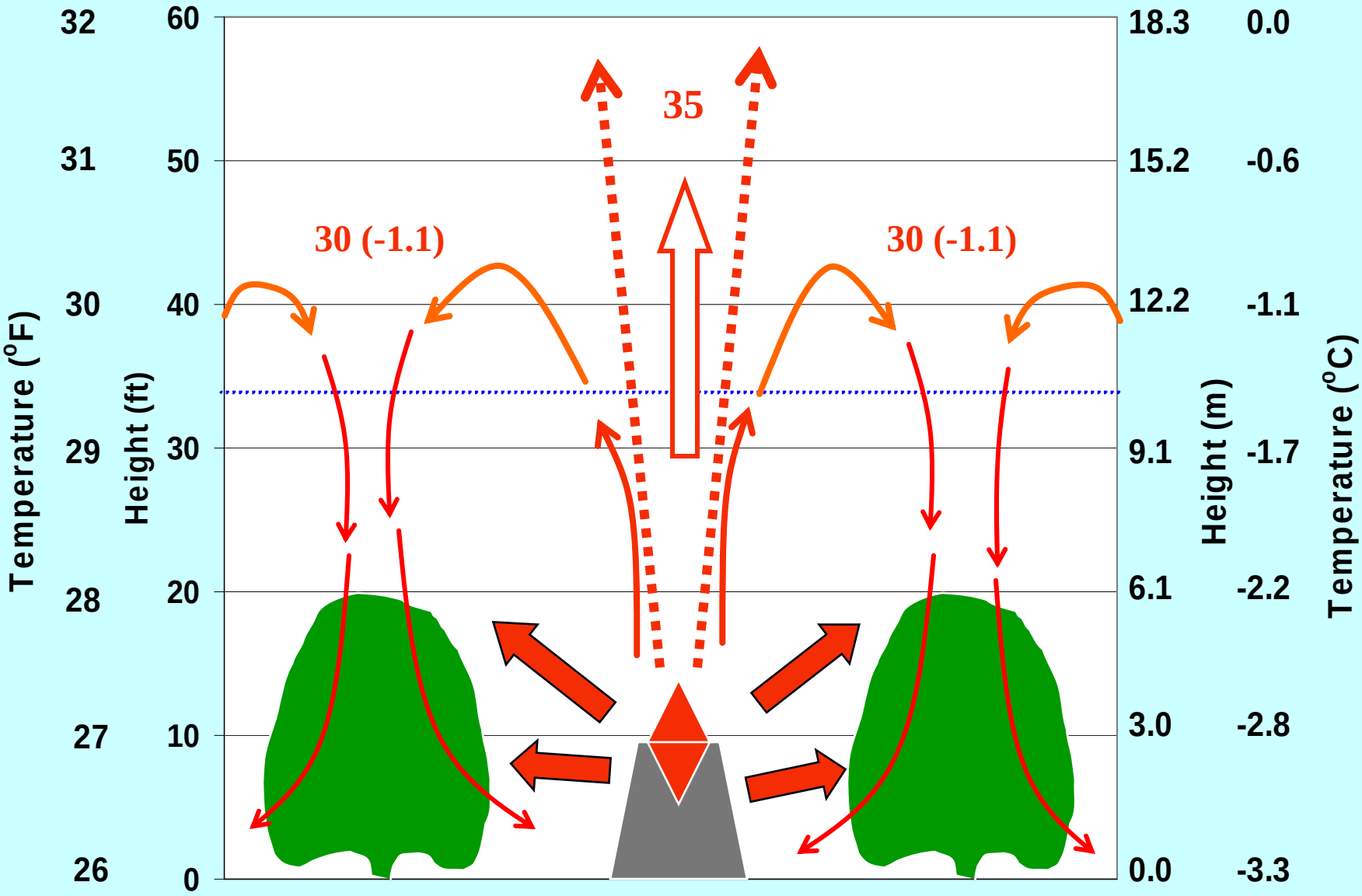
- **Heaters**
- **Wind Machines**
- **Helicopters**
- **Sprinklers**
- **Surface Water**
- **Foggers**

Heaters

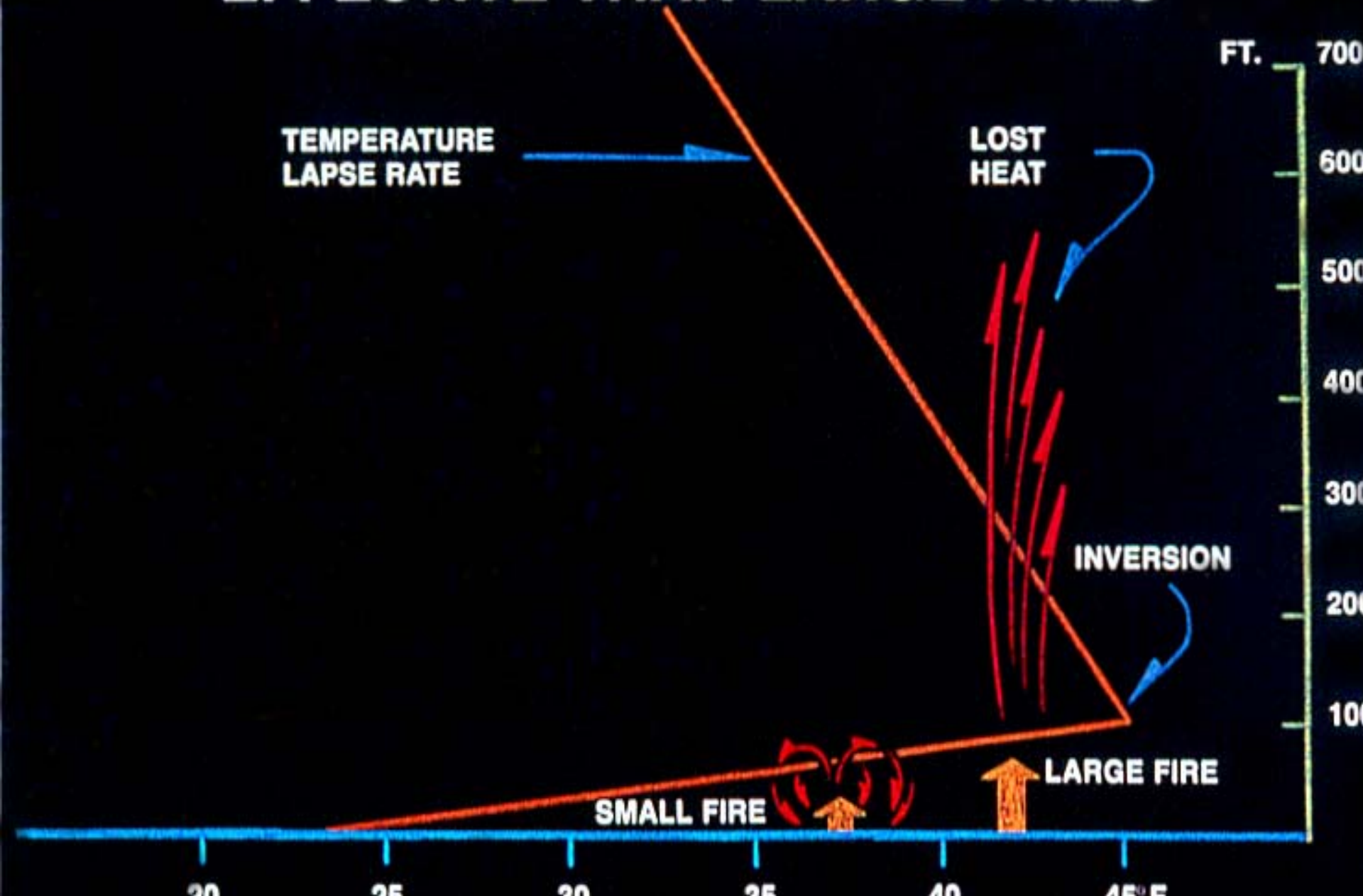
- Warm the trees through radiation and convection
- Inversions
- Small fires
- Low spots

UC Return Stack Orchard Heater – developed by Ag Engineering at UC Davis

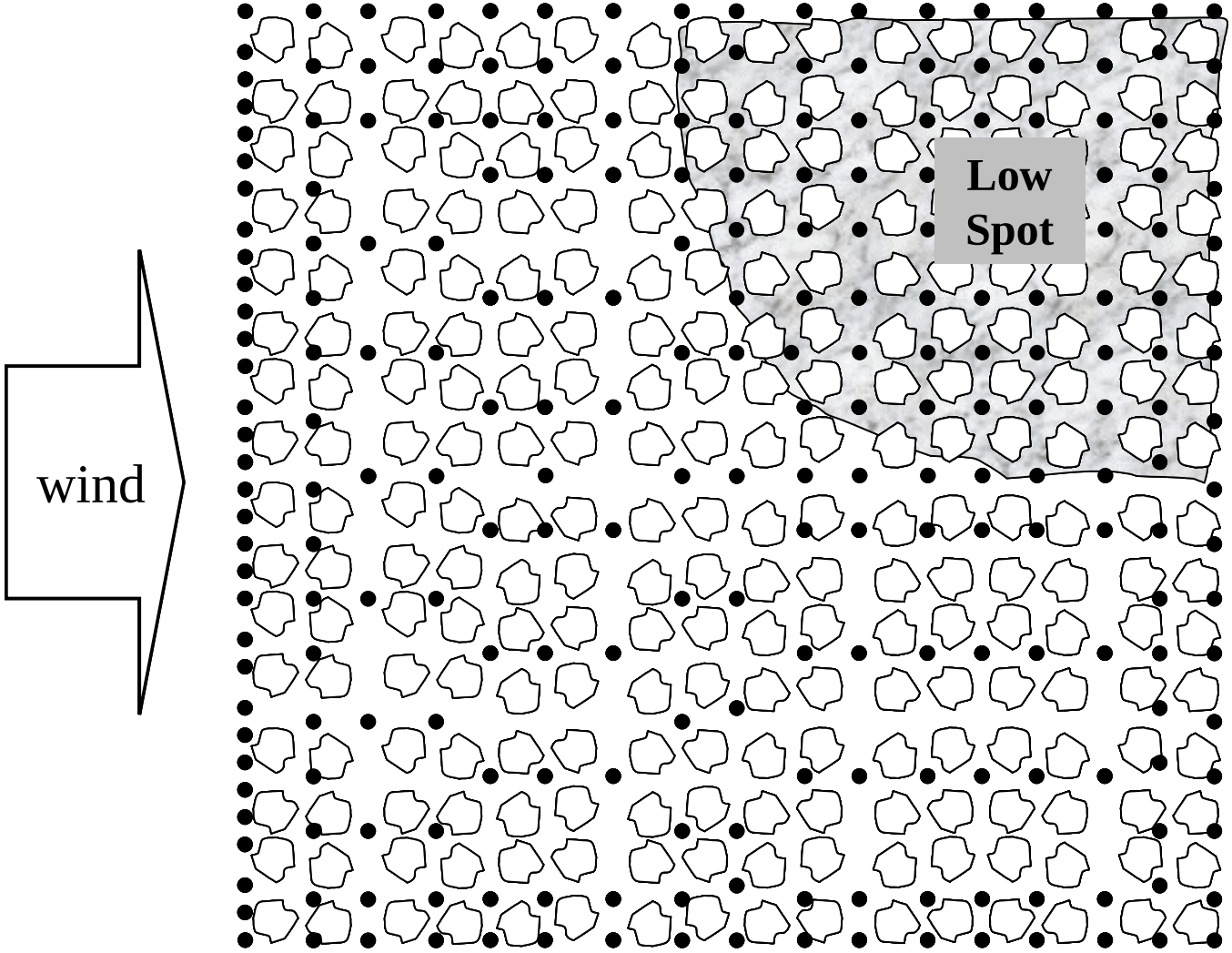
Heaters


32
31
30
29
28
27
26
Temperature (°F)
60
50
40
30
20
10
0
Height (ft)
18.3
15.2
12.2
9.1
6.1
3.0
0.0
Height (m)
0.0
-0.6
-1.1
-1.7
-2.2
-2.8
-3.3
Temperature (°C)
35
30 (-1.1)
30 (-1.1)

SMALL FIRES ARE MORE EFFECTIVE THAN LARGE FIRES

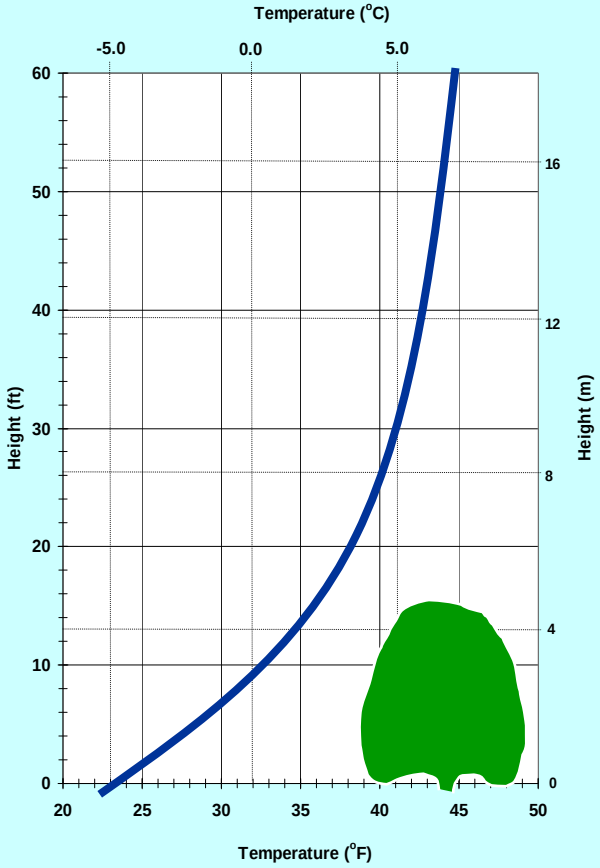


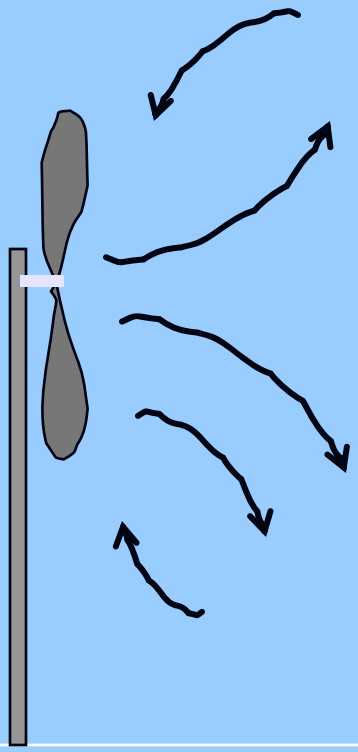
Heater placement



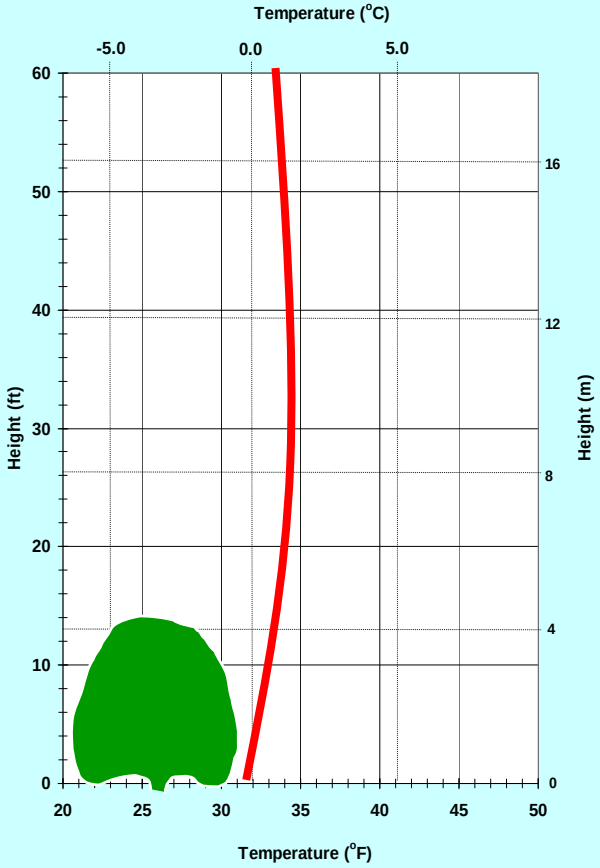
Wind Machines

No Wind Machine

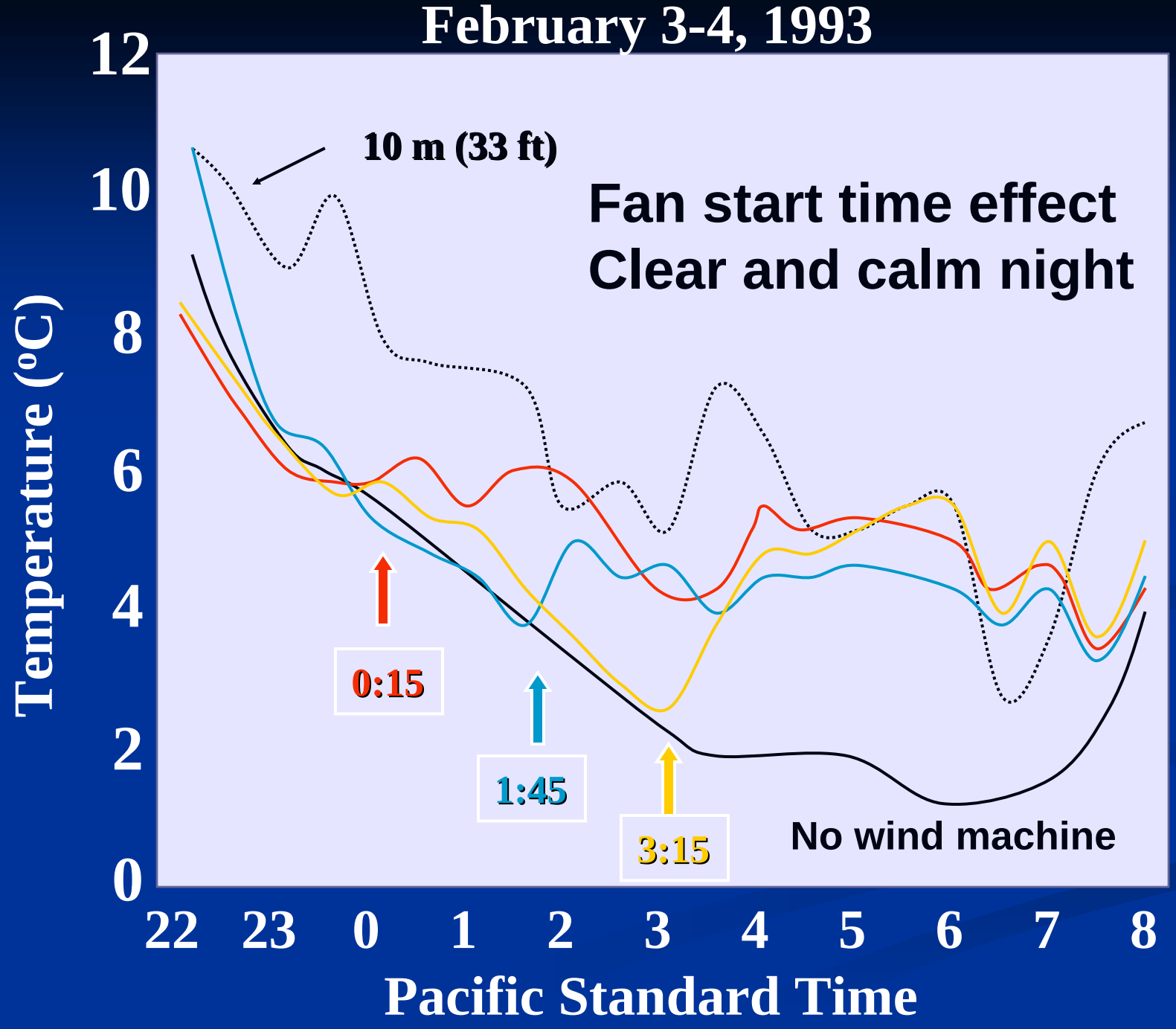


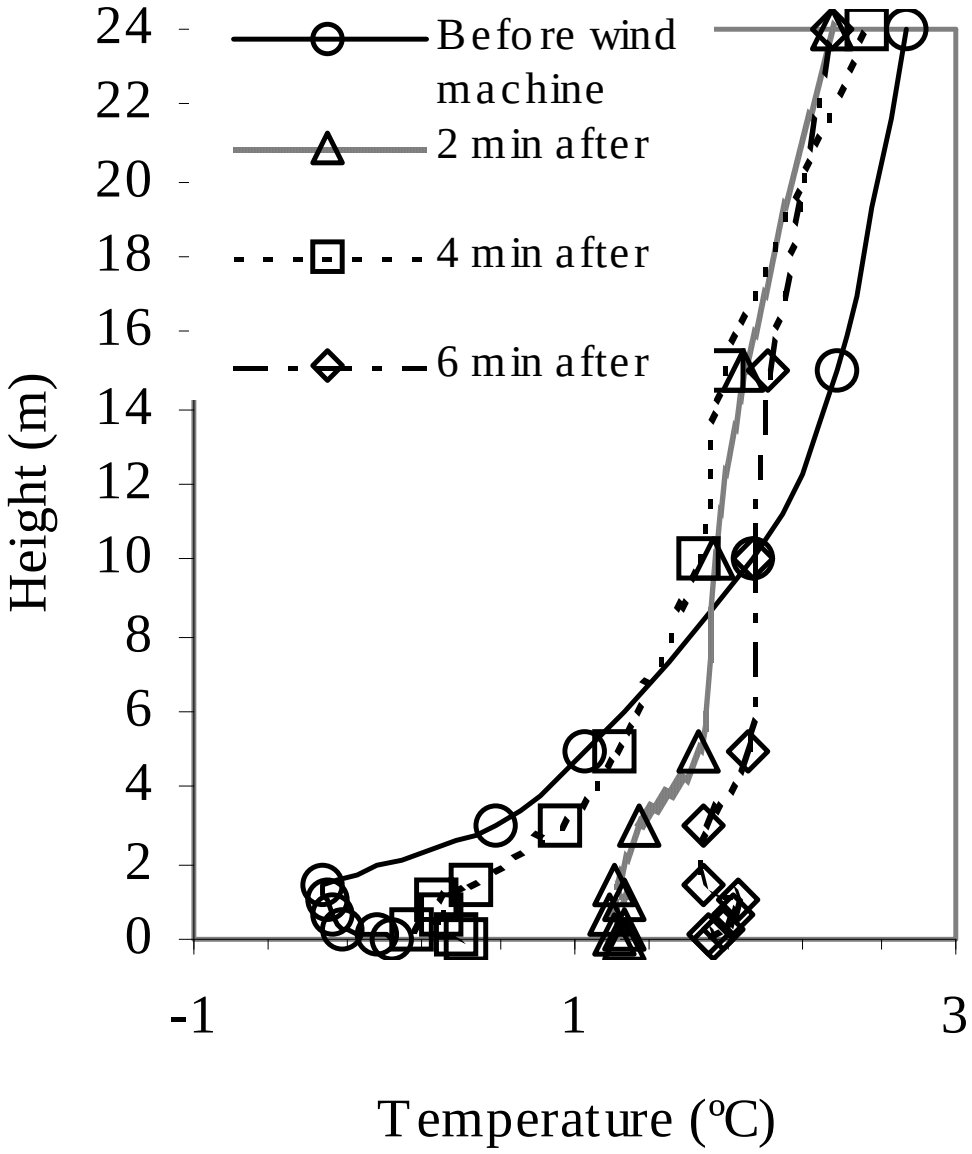


With Wind Machine



Wind machines work best in small narrow valleys with strong inversions


February 3-4, 1993
10 m (33 ft)
Fan start time effect
Clear and calm night
0:15
1:45
3:15
No wind machine
Temperature (°C)
12
10
8
6
4
2
0
22
23
0
1
2
3
4
5
6
7
8
Pacific Standard Time

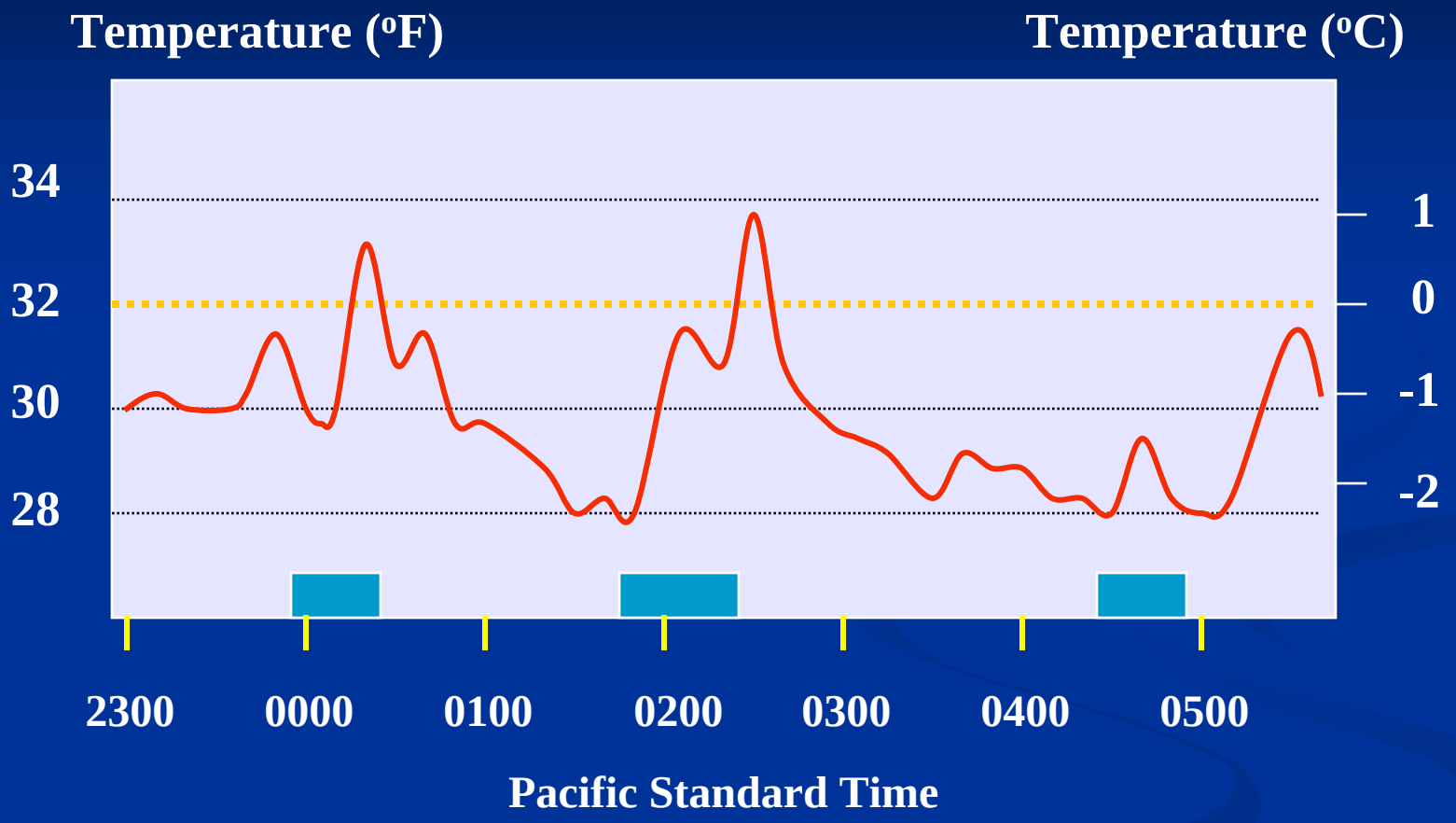


Temperature profiles (30 m from wind machine) before and after the wind machine was turned on

Helicopters…
are similar to wind machines

- **Push warm air down into the crop**
- **An inversion is required**

Helicopter Test



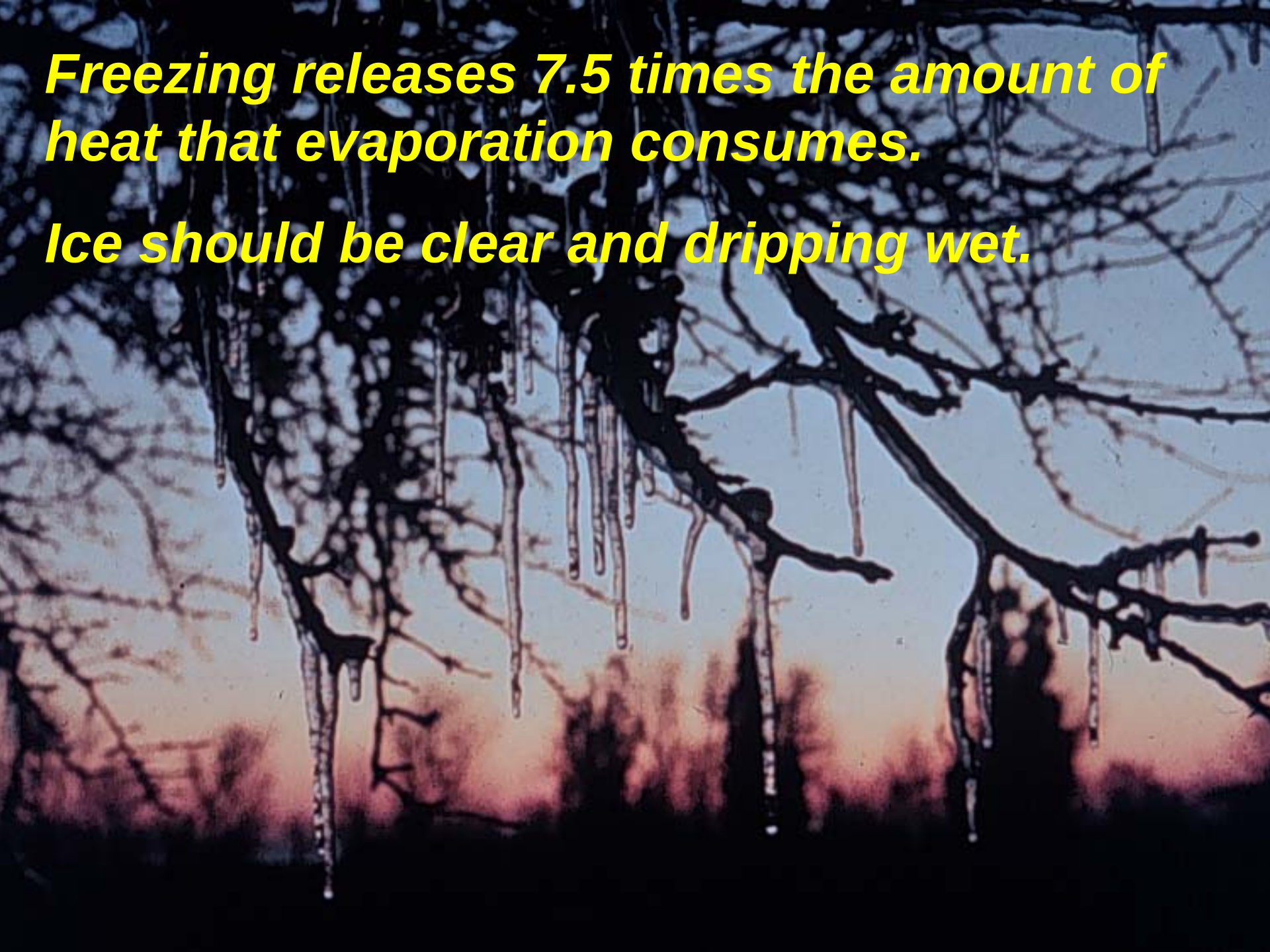
After Miller et al. (1951)

Helicopters

- Frequent passes
- Talk to the pilot
- Load with water
- Use marker lights
- Monitor temperature

Sprinklers

- **Heat gain is from freezing water and the release of latent heat**
- **Must add more energy from freezing than is lost to evaporation**
- **Start based on wet-bulb (critical damage temperature)**

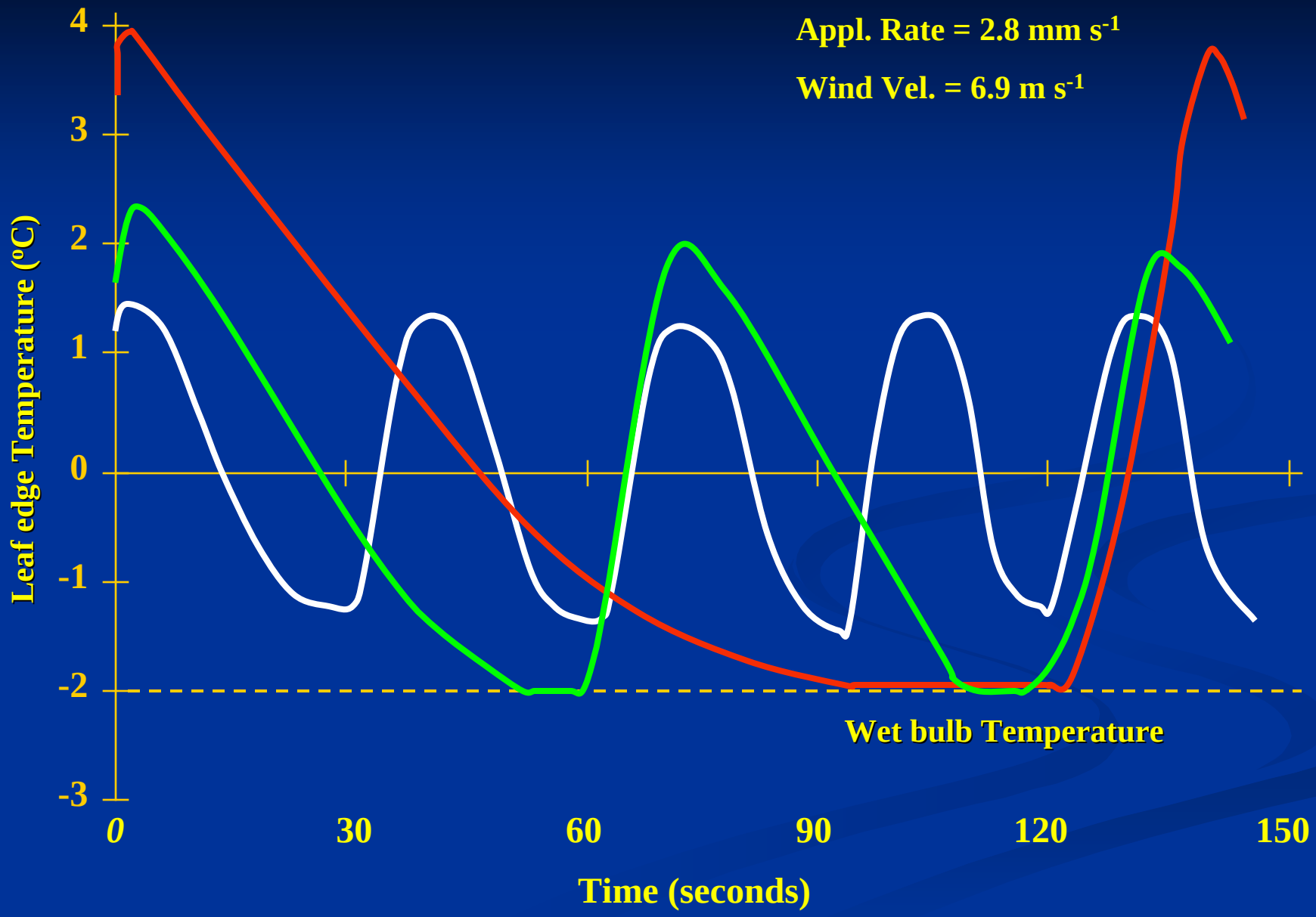

Freezing releases 7.5 times the amount of heat that evaporation consumes.
Ice should be clear and dripping wet.

Sprinklers…
solid set, movable aluminum pipes, or drag lines replaced orchard heaters

Micro-sprinklers work too if flow rate is sufficient

Application rates for freeze protection of tall crops

Temperature	Wind Speed	30 s rotation	60 s rotation
°F	mph	in/hr	in/hr
29	0.0-1.1	0.08	0.10
26	0.0-1.1	0.10	0.13
23	0.0-1.1	0.15	0.17
29	2.0-3.0	0.10	0.12
26	2.0-3.0	0.13	0.15
23	2.0-3.0	0.18	0.20
Temperature	**Wind Speed**	**30 s rotation**	**60 s rotation**
°F	mph	gpm/A	gpm/A
29	0.0-1.1	36	45
26	0.0-1.1	45	59
23	0.0-1.1	68	77
29	2.0-3.0	45	54
26	2.0-3.0	59	68
23	2.0-3.0	81	90


Appl. Rate = 2.8 mm s-1
Wind Vel. = 6.9 m s-1
Leaf edge Temperature (ºC)
4
3
2
1
0
-1
-2
-3
Wet bulb Temperature
0
30
60
90
120
150
Time (seconds)

Nuts in the tree top above the cold air

No nuts in the middle canopy above the sprinkler pattern… shoot growth instead

Nuts in the bottom canopy where sprinklers provided coverage & protection

Turn on Temperatures for Sprinklers

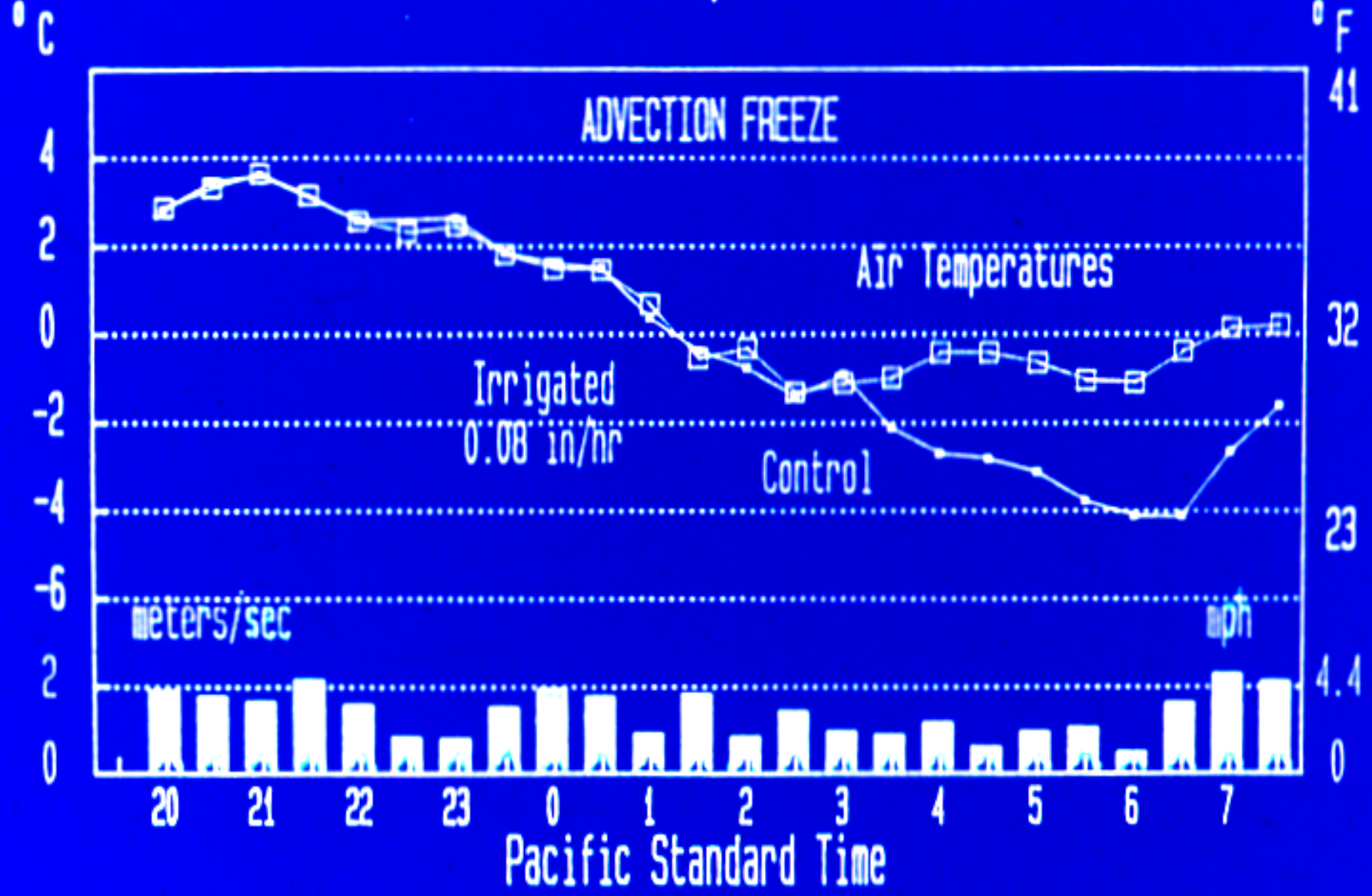
Dew-point Temperature	Wet-bulb Temperature (°F)										
°F	22	23	24	25	26	27	28	29	30	31	32
32											32.0
31										31.0	32.7
30									30.0	31.7	33.3
29								29.0	30.6	32.3	34.0
28							28.0	29.6	31.2	32.9	34.6
27						27.0	28.6	30.2	31.8	33.5	35.2
26					26.0	27.6	29.2	30.8	32.4	34.0	35.7
25				25.0	26.5	28.1	29.7	31.3	32.9	34.6	36.3
24			24.0	25.5	27.1	28.6	30.2	31.8	33.5	35.1	36.8
23		23.0	24.5	26.0	27.6	29.1	30.7	32.3	34.0	35.6	37.3
22	22.0	23.5	25.0	26.5	28.1	29.6	31.2	32.8	34.5	36.1	37.8
21	22.5	24.0	25.5	27.0	28.5	30.1	31.7	33.3	34.9	36.6	38.2
20	22.9	24.4	25.9	27.4	29.0	30.6	32.1	33.7	35.4	37.0	38.7
19	23.4	24.9	26.4	27.9	29.4	31.0	32.6	34.2	35.8	37.5	39.1
18	23.8	25.3	26.8	28.3	29.8	31.4	33.0	34.6	36.2	37.9	39.5
17	24.2	25.7	27.2	28.7	30.2	31.8	33.4	35.0	36.6	38.3	39.9
16	24.6	26.1	27.6	29.1	30.6	32.2	33.8	35.4	37.0	38.7	40.3
15	25.0	26.4	27.9	29.5	31.0	32.6	34.2	35.8	37.4	39.0	40.7

When to turn off sprinklers?

- **Turn off when the wet bulb temp. upwind of the protected orchard is above the critical damage temperature**
- **Or, when all the ice melts**

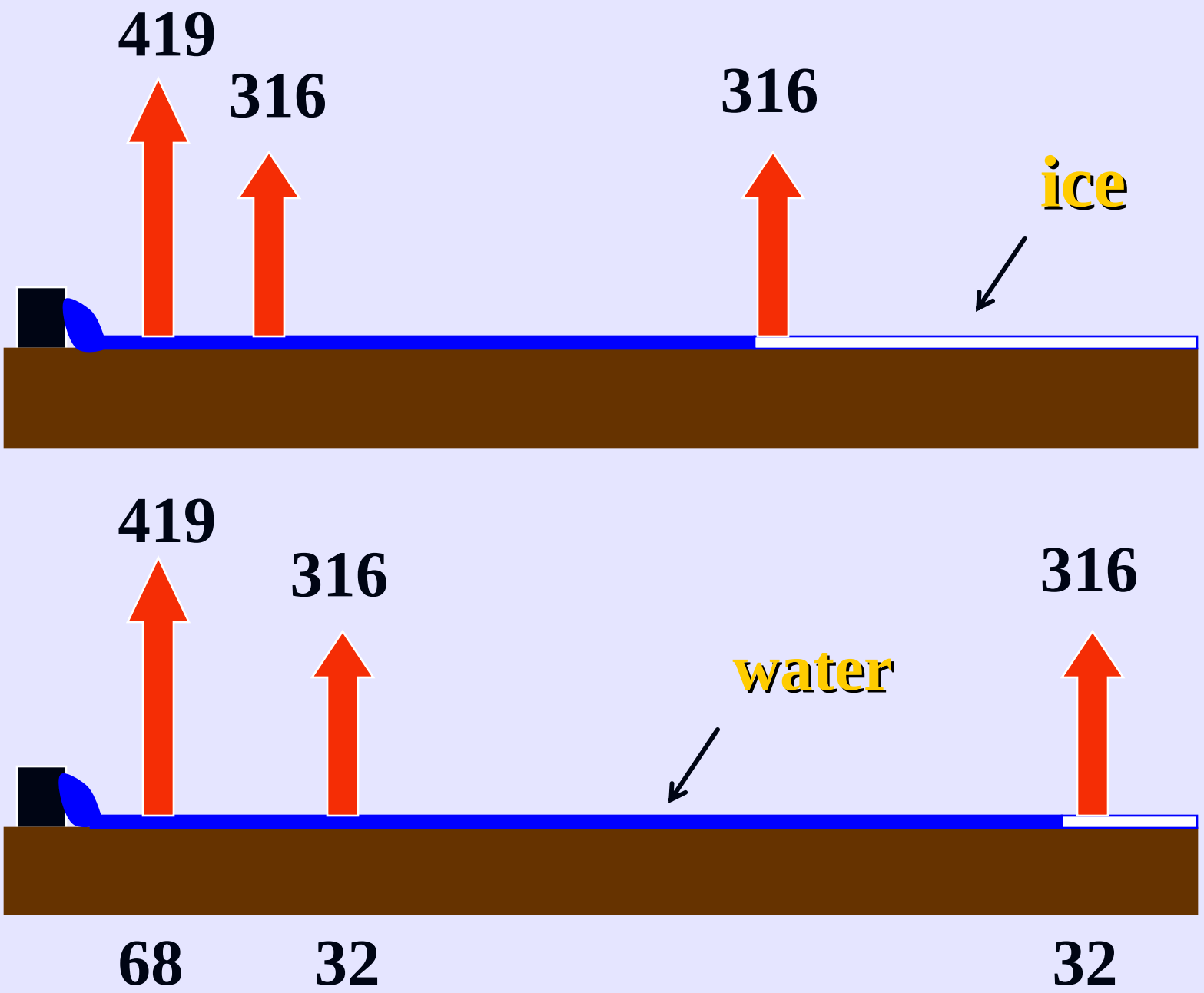
Under Tree Sprinklers

Feb 3-4, 1989



Surface irrigation

- **Either flood or furrow**
- **Provides protection thru latent heat released as the water cools**


419
316
316
ice
419
316
316
water
68
32
32

Surface irrigation

- Concentrate the flooding in furrows under the tree canopy
- Use a fast flow rate to prevent freezing
- Don’t reuse cold water
- Maximize the area wetted before the expected frost night to store more heat during the day
- Start early

Foggers

- Provide protection by creating an insulating blanket that reduces net radiation losses.

The Mee System – uses high pressure water and small orifices to produce a fog curtain.

Vapor Gun – propane burner used to vaporize water.

Summary: of all the options available today ---

- **Under tree sprinkling is probably the most effective and practical**
  - **Solid set irrigation, movable pipe, or micro-sprinklers can provide benefits**
  - **40 gpm/acre is an application rate that will be effective in most frost conditions we experience**

Acknowledge my cooperator of many years

Dr. Richard Snyder, Extension Biometeorologist, UC Davis.

For more information visit his dept. web site:

http://lawr.ucdavis.edu/coopextn/biometeorology/