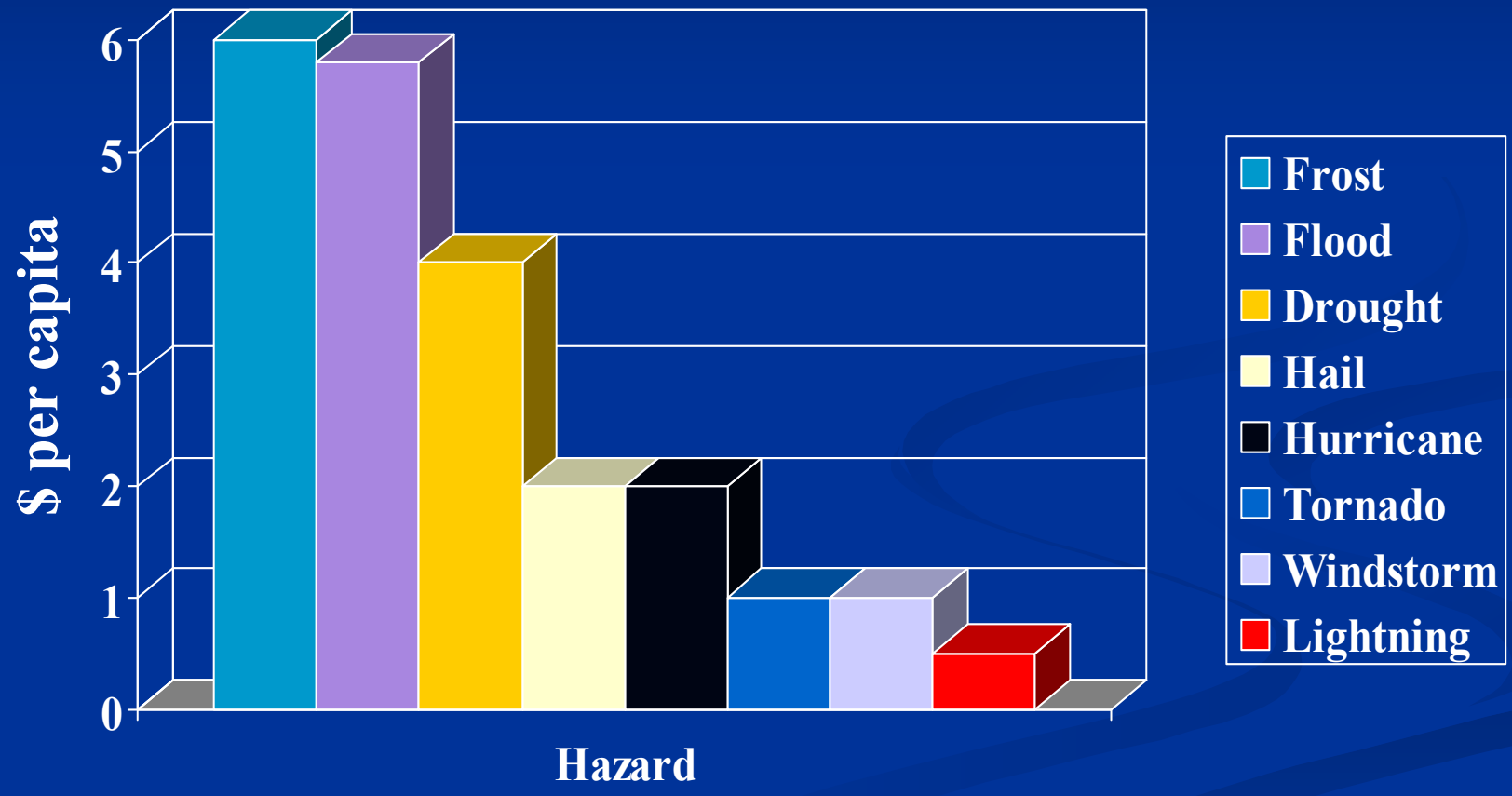
Frost Protection Principles

Joe Connell
UC Farm Advisor, Butte County

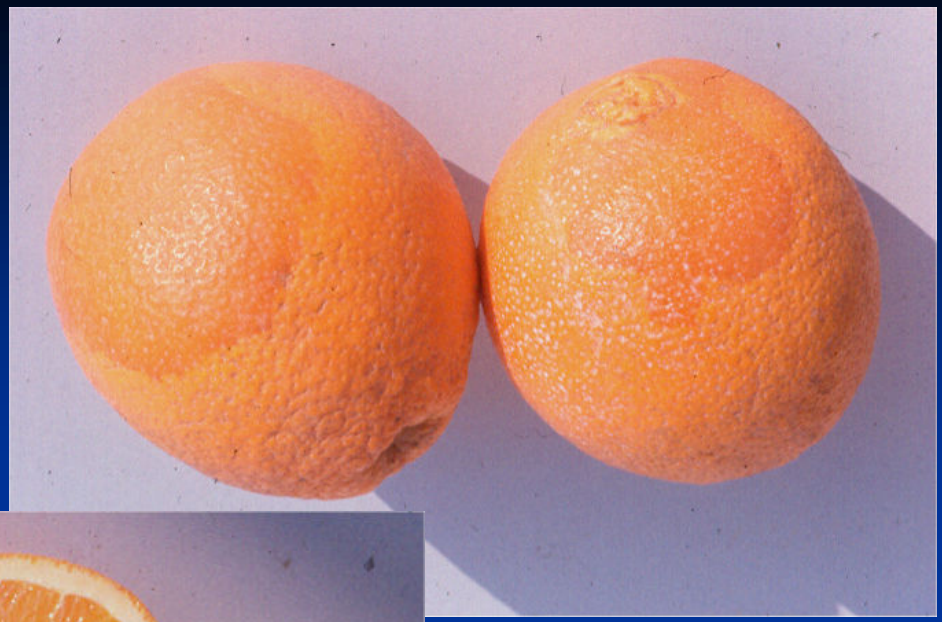
University of California
Cooperative Extension

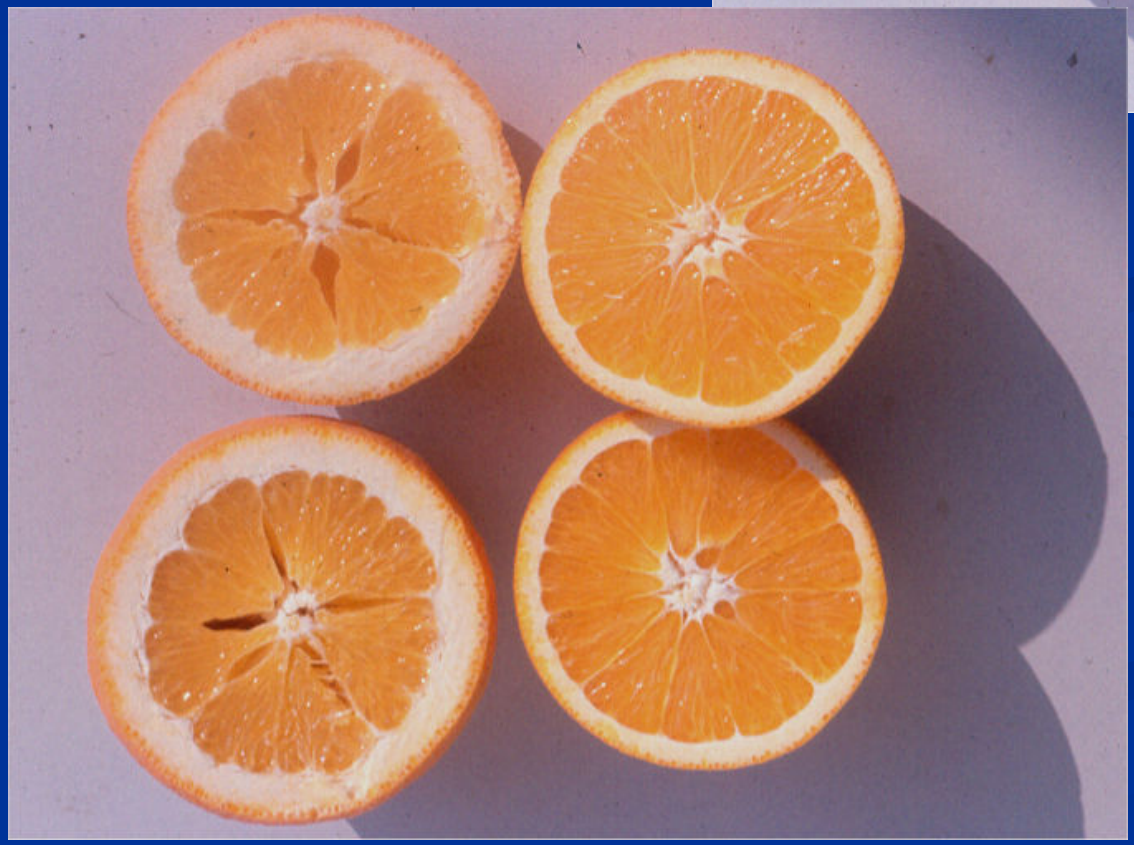
Agriculture & Natural Resources
Central Valley Region

Mean Annual Losses to Weather Hazards in the United States



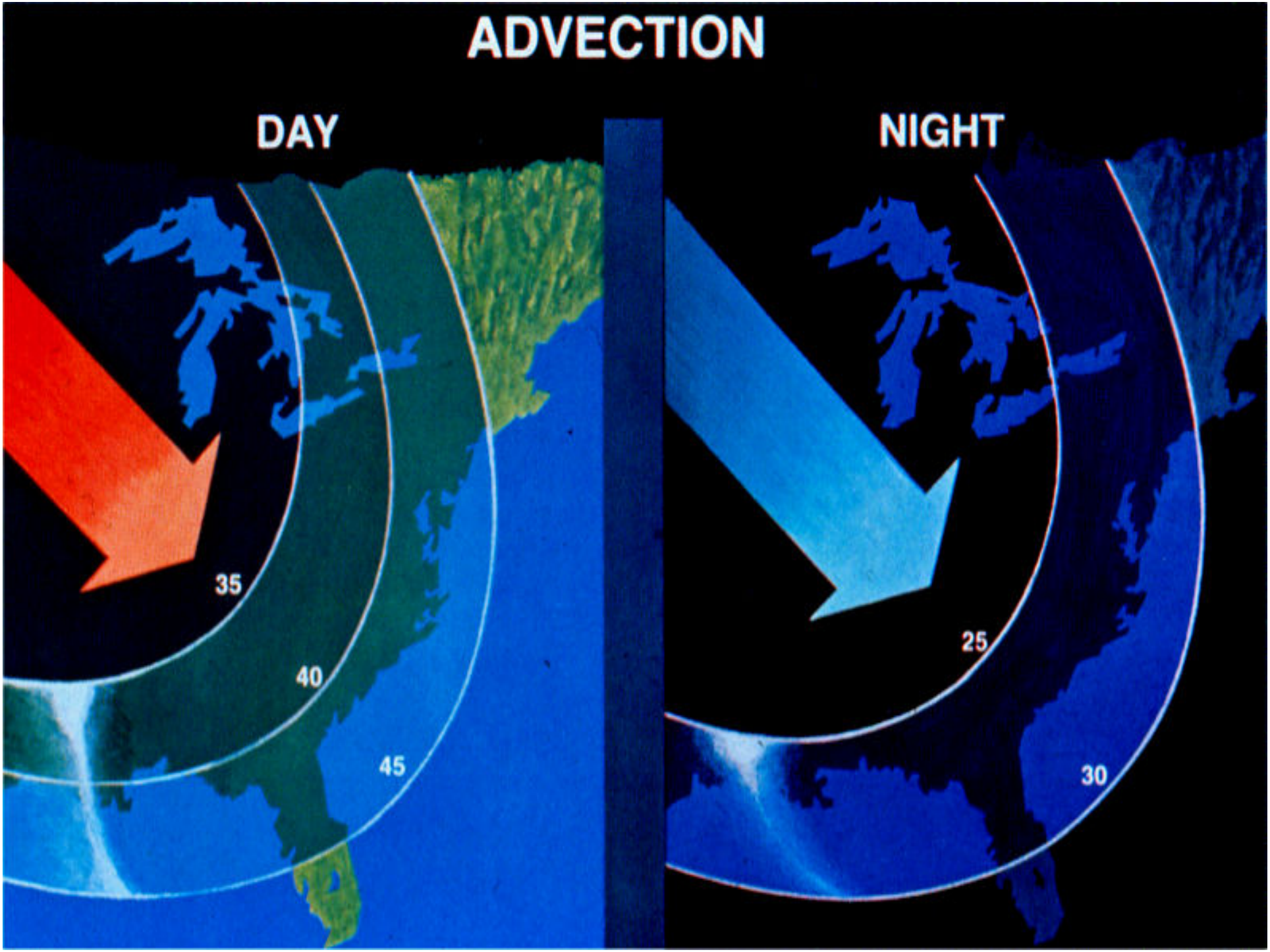
Water soaking freeze injury on left and top





Fruit on right not frozen

Ice marking


ADVECTION
DAY
NIGHT
35
40
45
25
30

Advection Freeze in 1990 – an Arctic Air Mass

Advection Freeze in 1990 – an Arctic Air Mass

Radiation

Day

Night

Methods of Heat Transfer

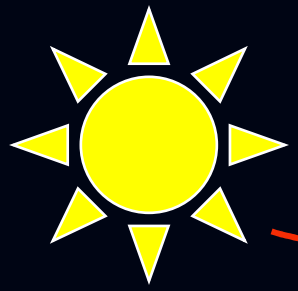
Conduction- from molecule to molecule

Heat Source

Metal bar

Convection - by movement of heated air

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



Long wave loss from Earth

Short wave gained from the sun

Properties of Water

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

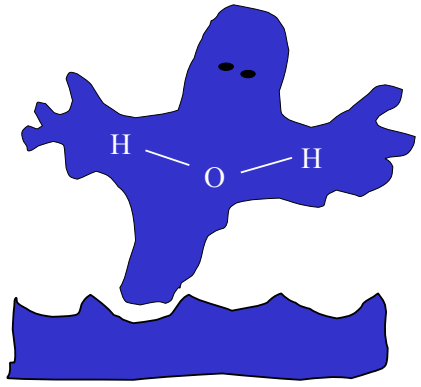
Latent Heat

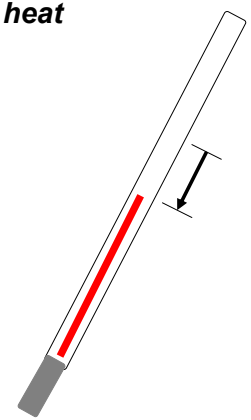
- Heat Stored in Water
- Chemical Energy
- Hydrogen Bonds

Methods of Heat Transfer

Latent Heat – Chemical Heat

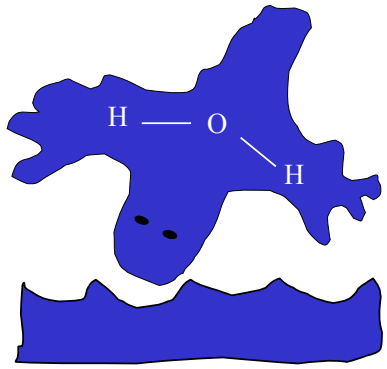
When water molecules evaporate, sensible heat is changed to latent heat and the temperature drops

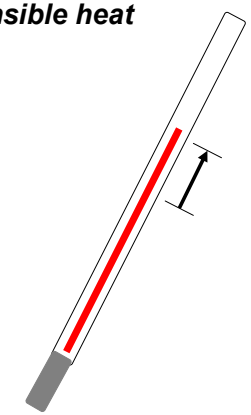




Evaporation

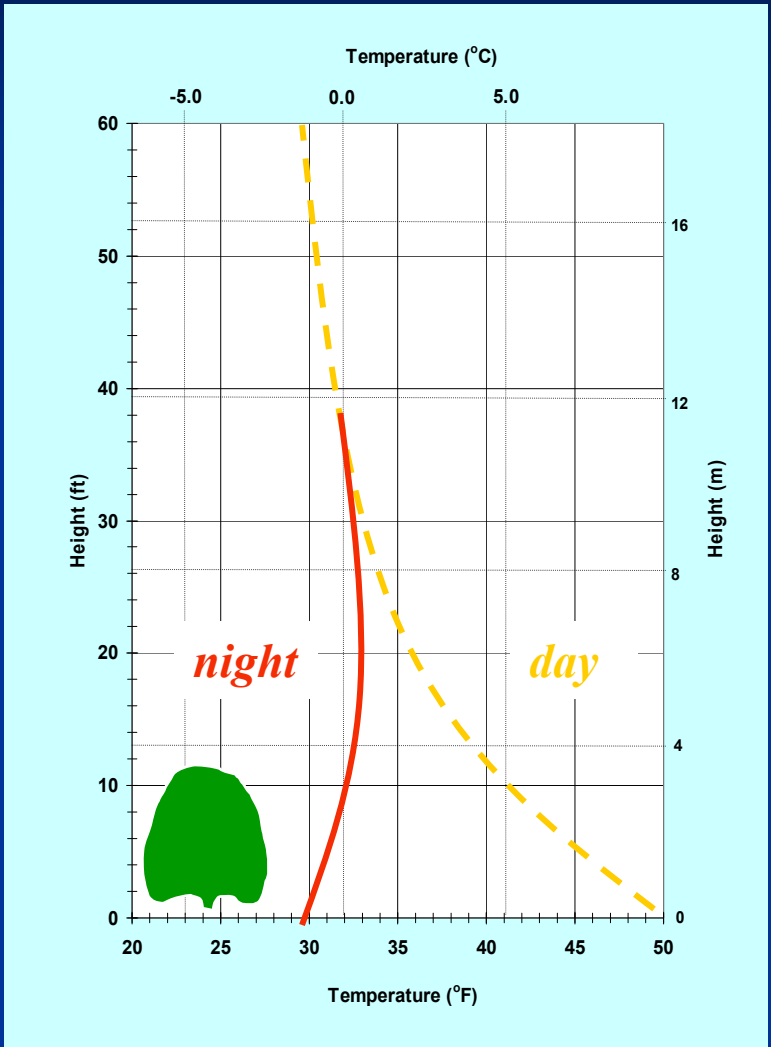
When water molecules condense, latent heat is changed to sensible heat and the temperature rises



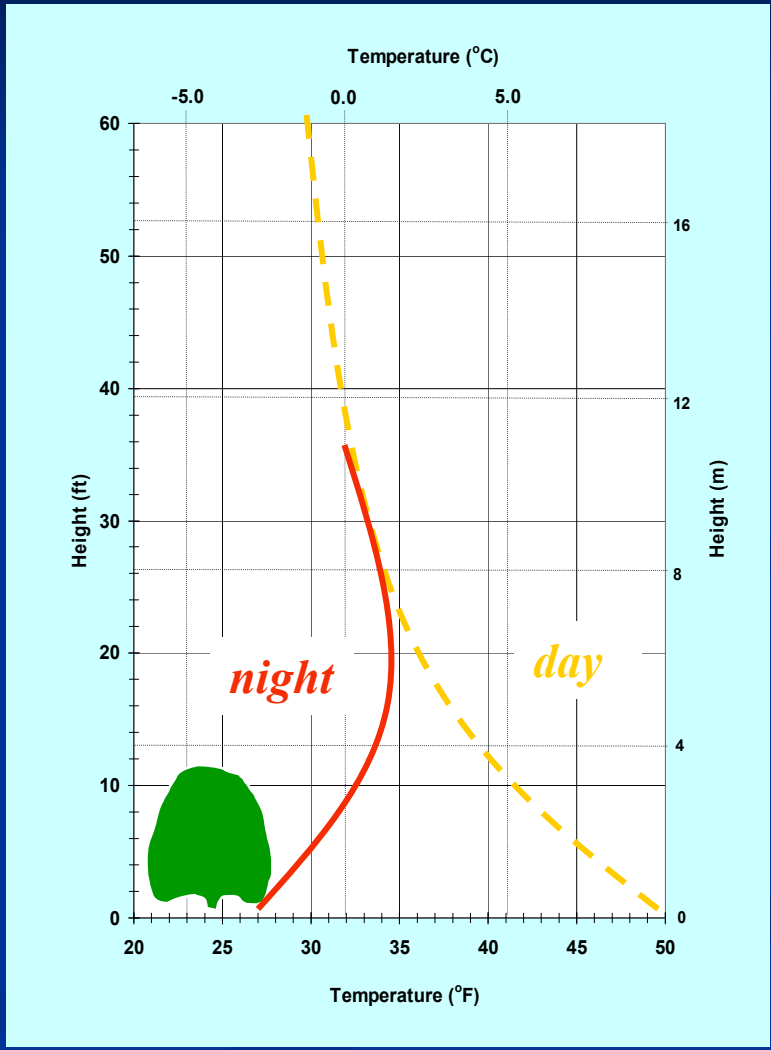


Condensation

High Humidity



Low Humidity

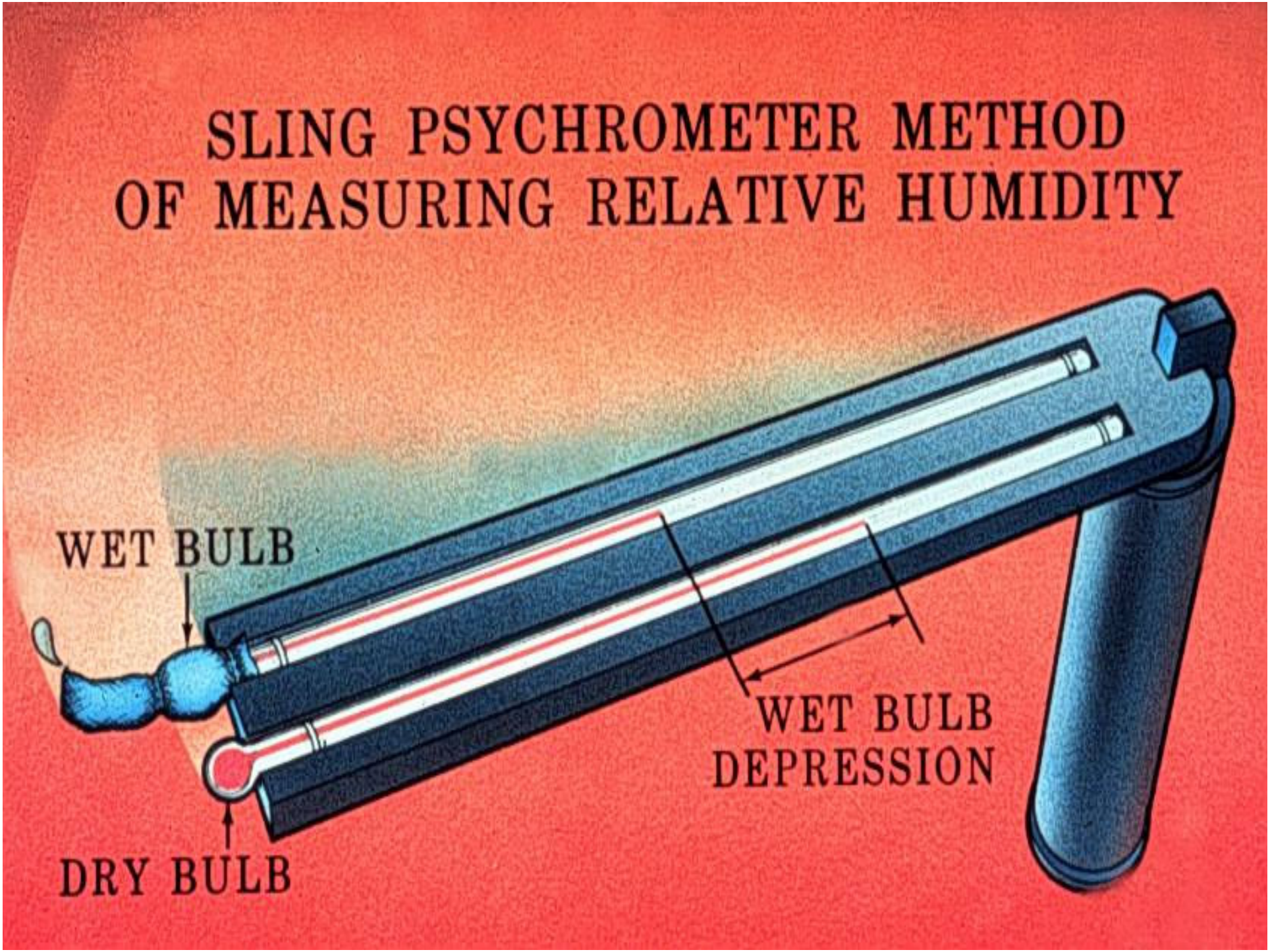


High humidity slows the decline of overnight temperatures

Water Vapor Concentration

- The higher the concentration the higher the humidity.
- When water vapor saturates, the thermometer reads the wet-bulb temperature.
- A wet plants temperature cannot fall below the wet-bulb temperature.

SLING PSYCHROMETER METHOD OF MEASURING RELATIVE HUMIDITY

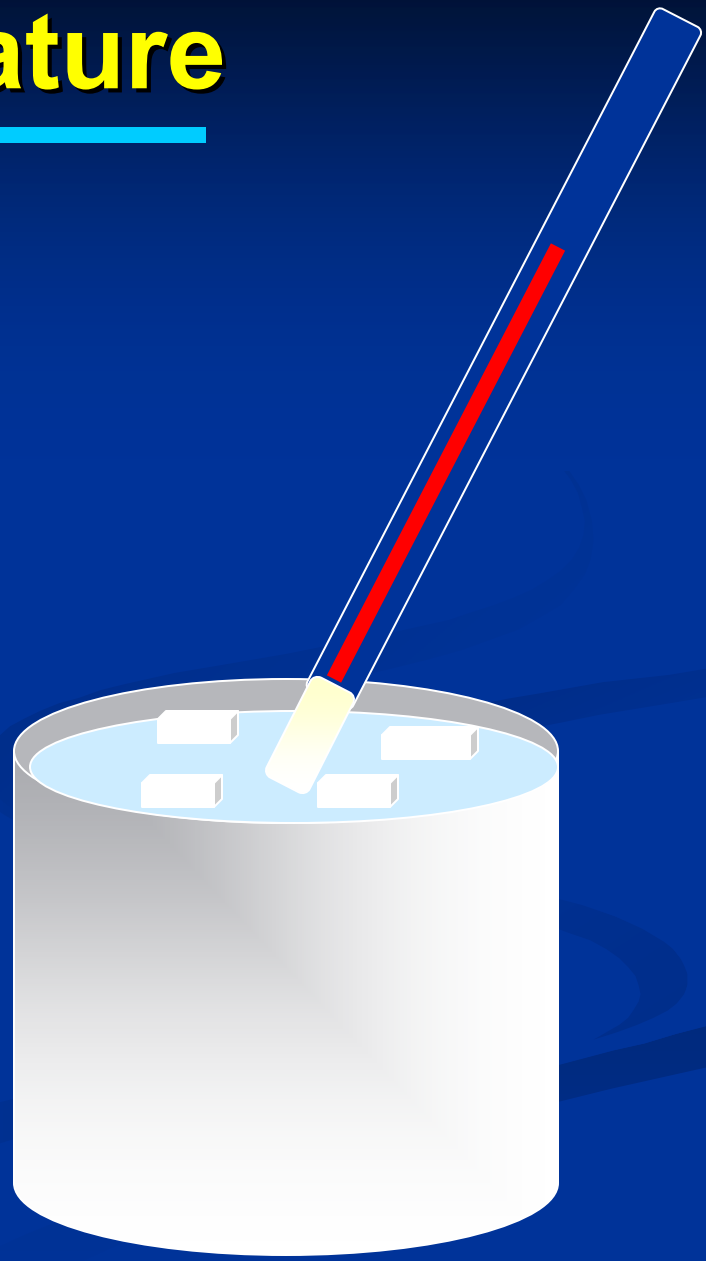


Dew Point

- Dew point is the temperature when relative humidity = 100 %.
- When the surface temperatures reach the dew point, condensation (dew) forms releasing sensible heat which slows the temperature drop.

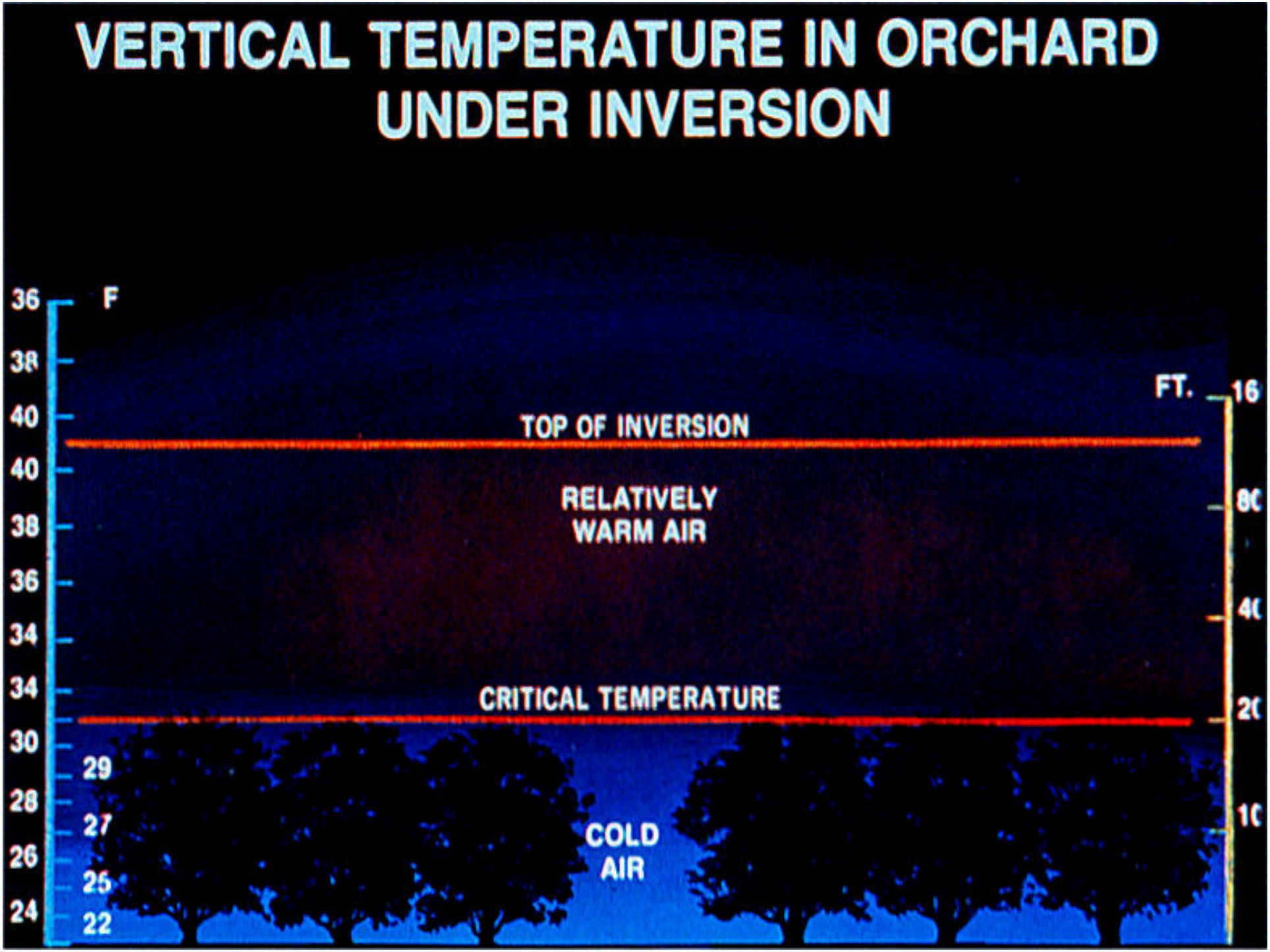
Dew point Temperature

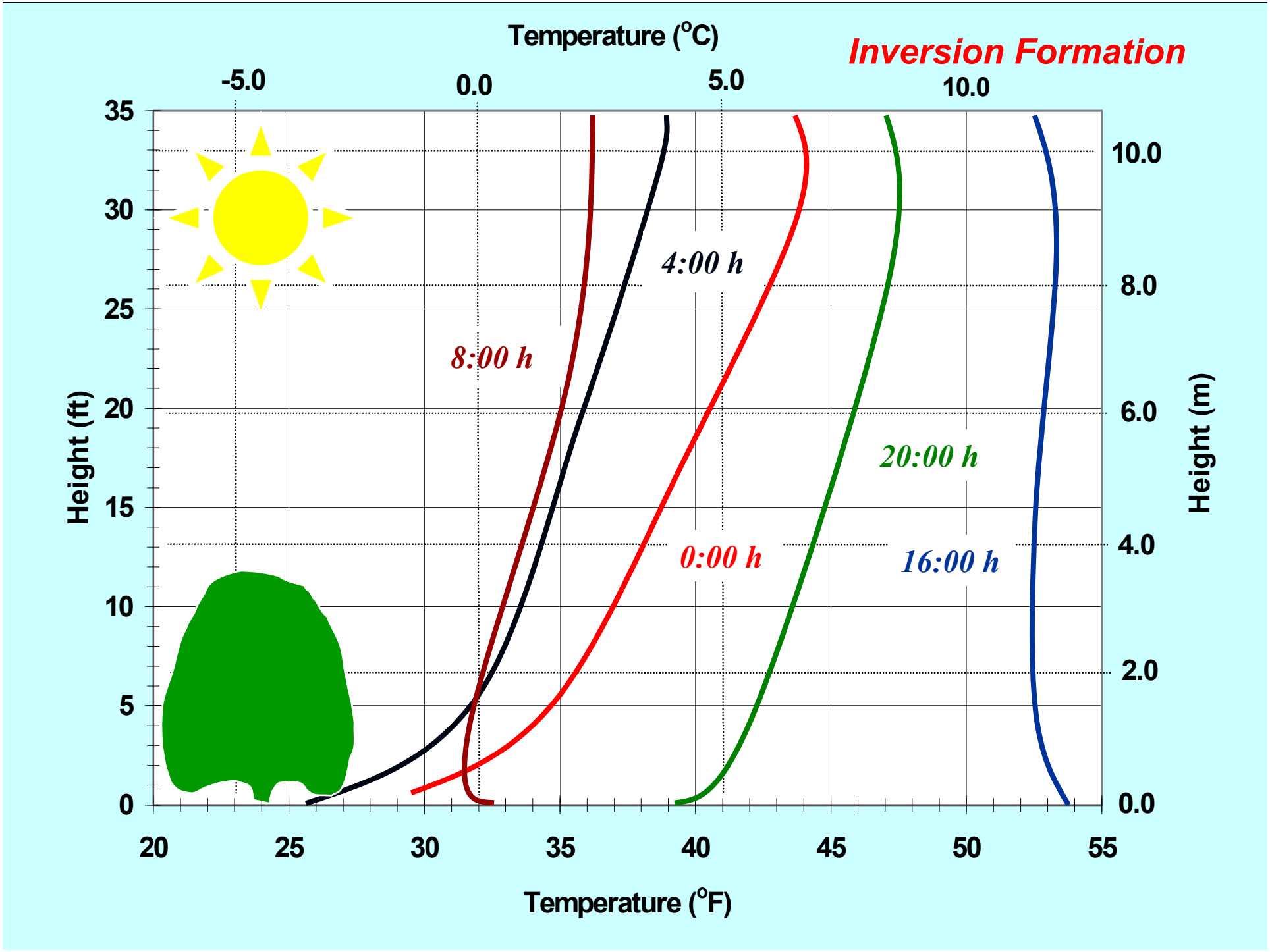
- ✓ Slowly add ice cubes to the water in a shiny can to lower the can temperature.
- ✓ Stir the water with a thermometer while adding ice cubes to insure the same can and water temperature.
- ✓ When condensation occurs on the outside, note the dew point temperature.

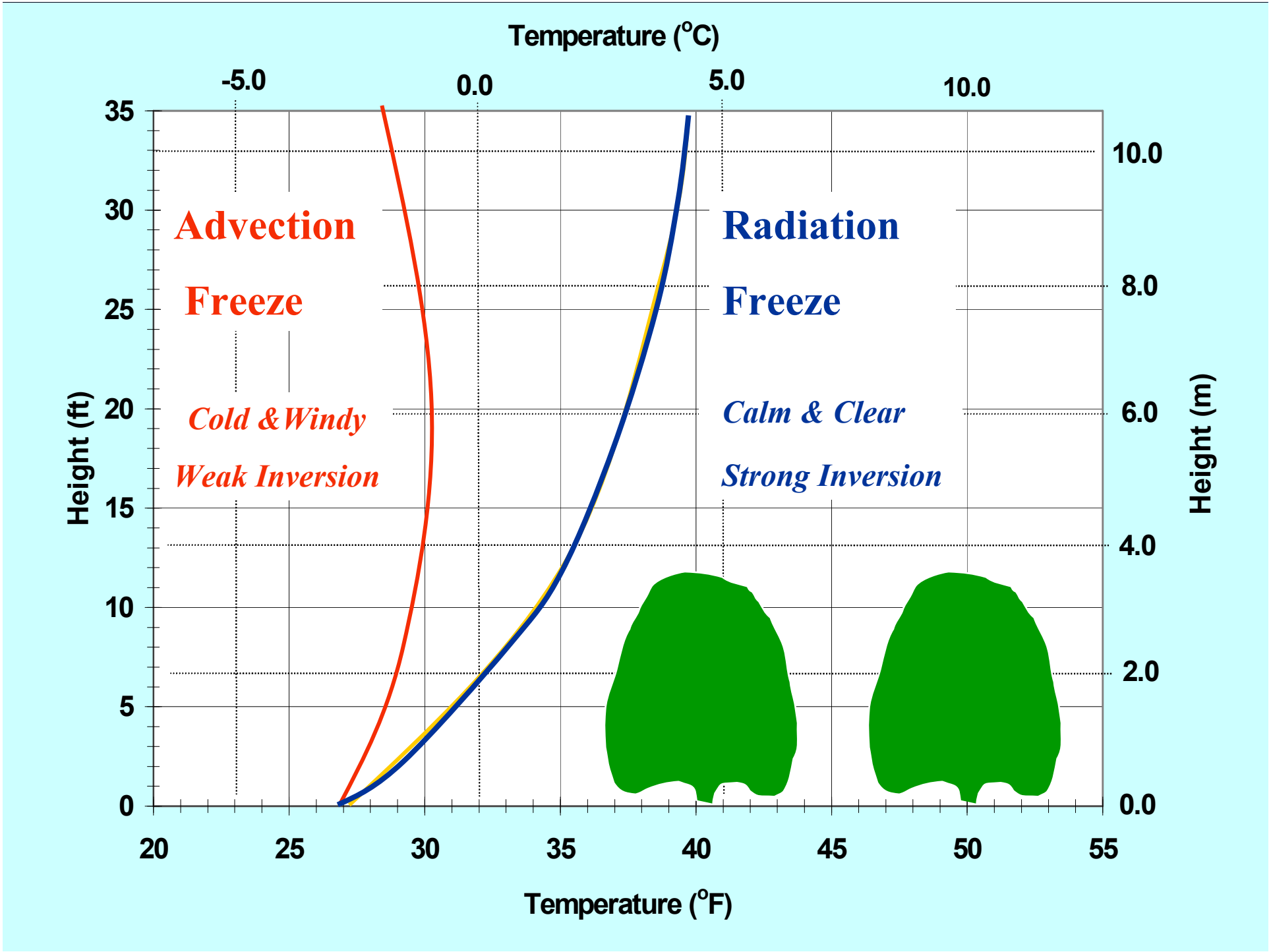


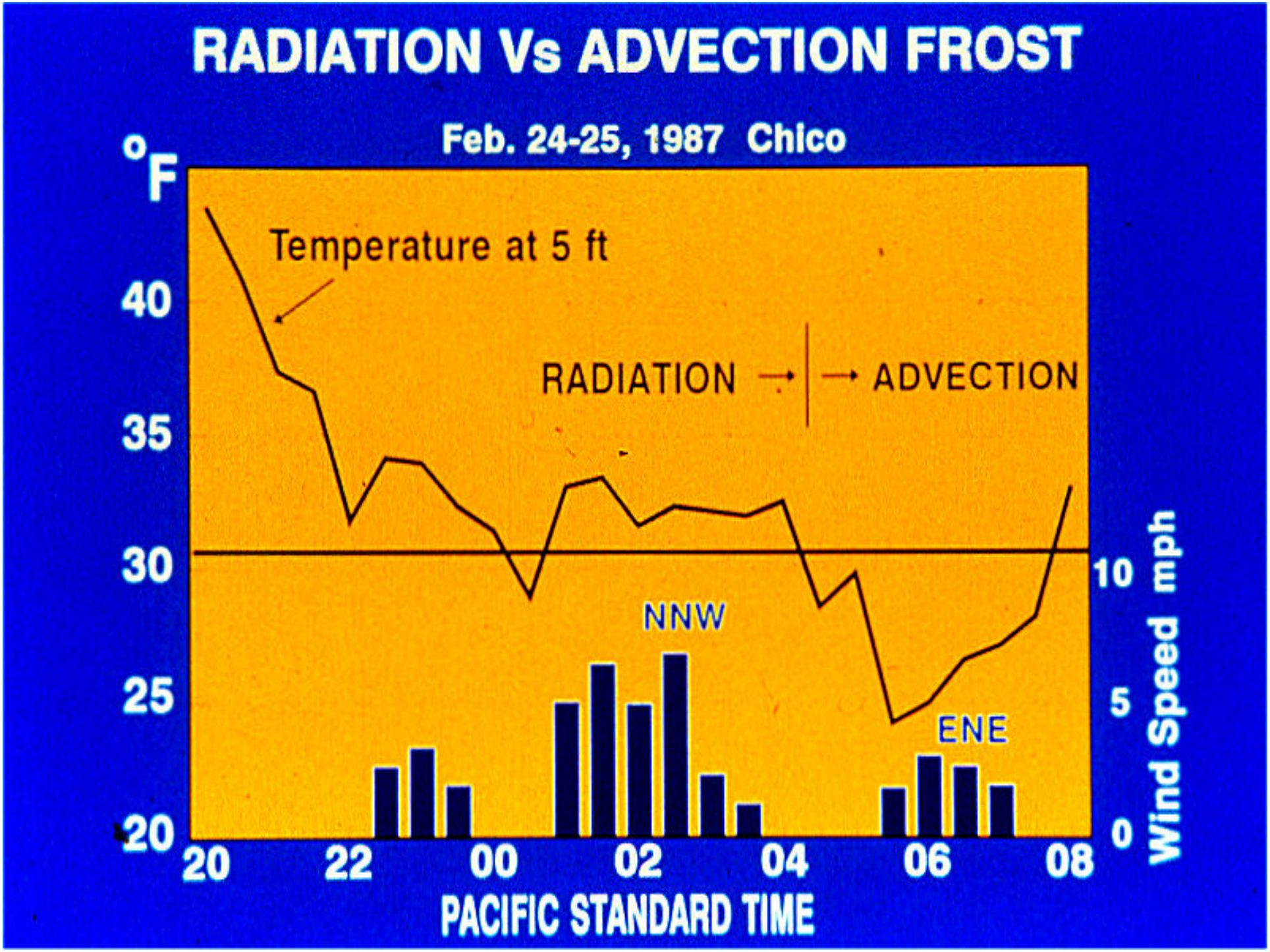
An inversion…

- Occurs when temperature increases with height.
- Forms when air near the ground cools more rapidly than the air above.
- Associated with radiation freezes.


VERTICAL TEMPERATURE IN ORCHARD
UNDER INVERSION
36
F
38
40
40
38
36
34
34
30
29
28
27
26
25
24
22
FT.
16
8(
4(
2(
1(
TOP OF INVERSION
RELATIVELY
WARM AIR
CRITICAL TEMPERATURE
COLD
AIR


Inversion Formation
Temperature (°C)
-5.0
0.0
5.0
10.0
Height (ft)
Height (m)
35
30
25
20
15
10
5
0
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
Feb. 24-25, 1987 Chico
°F
Temperature at 5 ft
RADIATION
ADVECTION
40
35
30
25
20
NNW
ENE
10
5
0
Wind Speed mph
20
22
00
02
04
06
08
PACIFIC STANDARD TIME

Elements of Passive Frost Protection

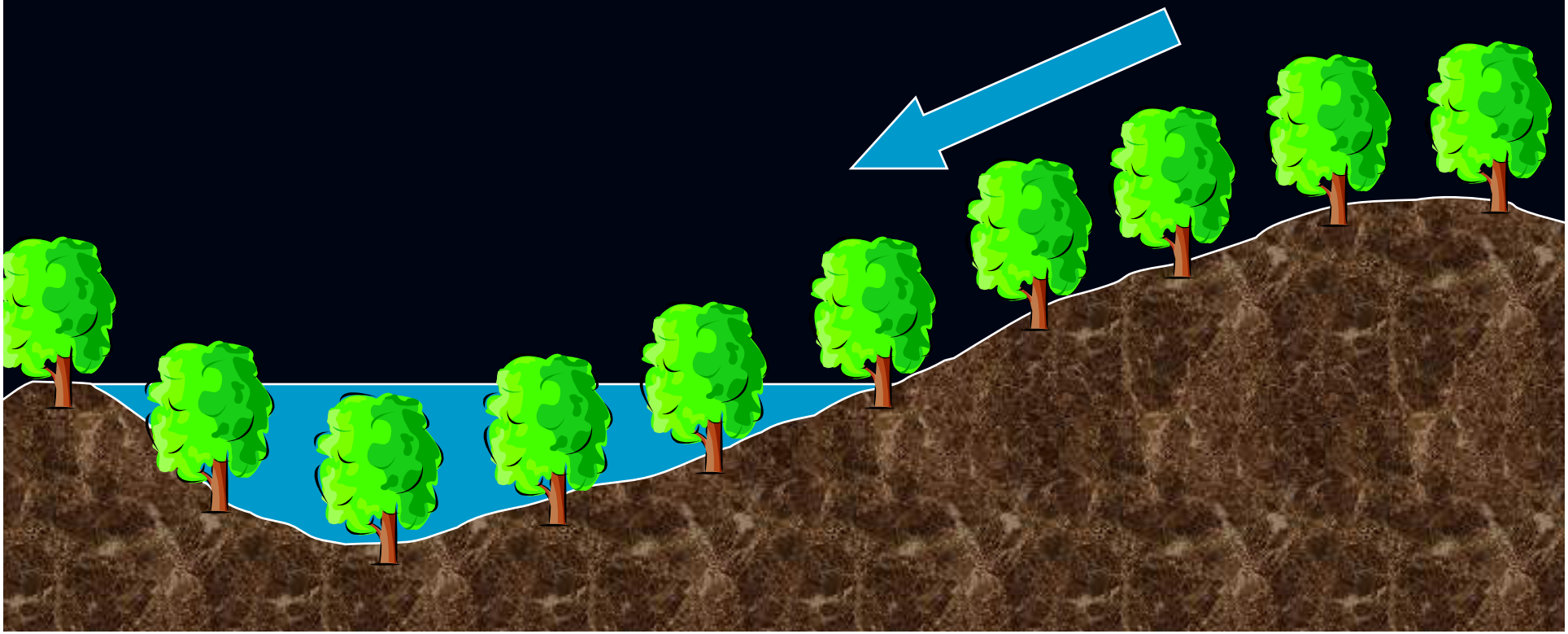
- Site Selection
- Ground Cover
- Soil Water Content
- Covers & Wraps
- Bacteria Control

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

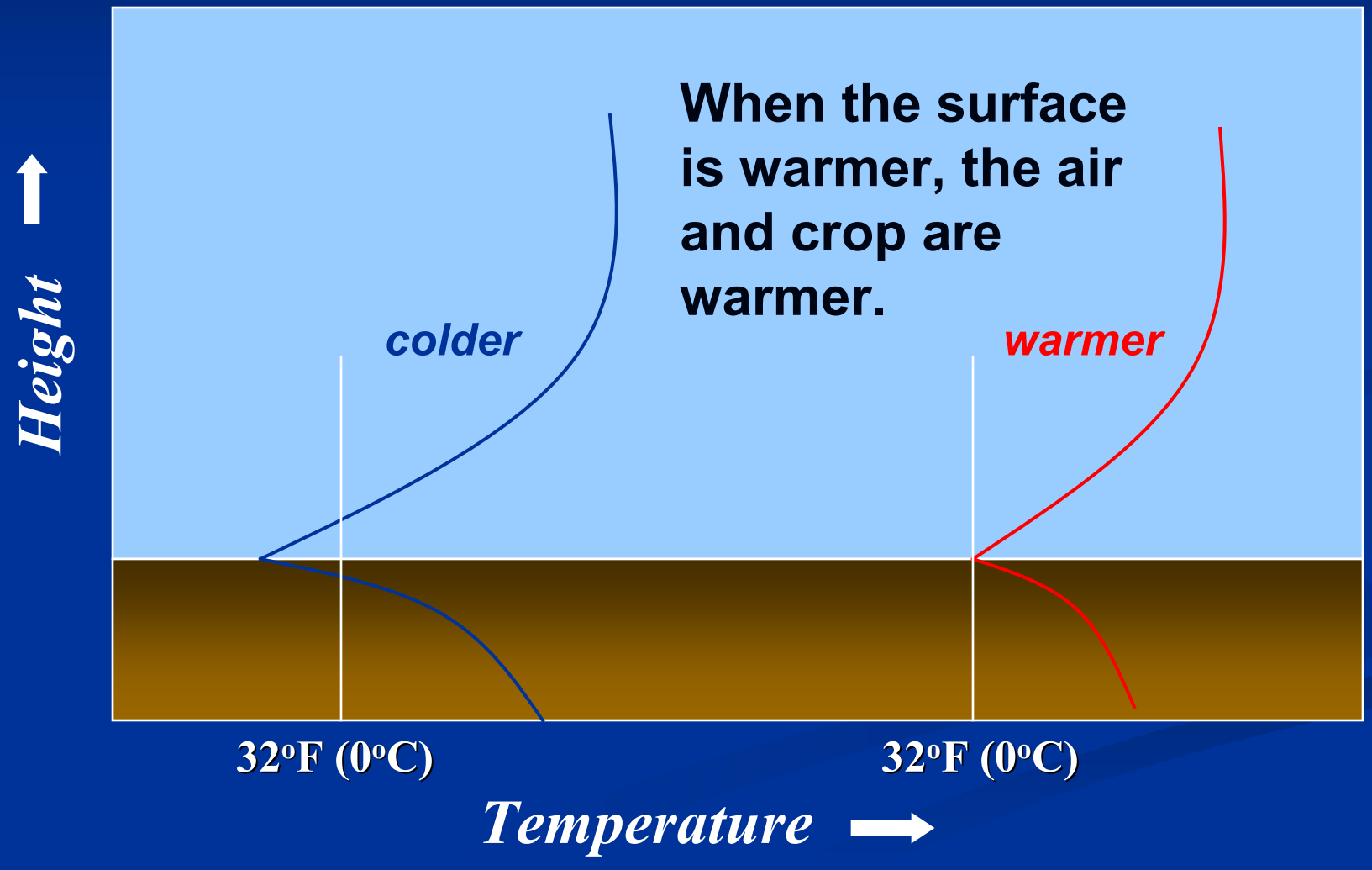


Freeze along Highway 65, Porterville, CA

Site Selection

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

Surface temperature affects the air and crop temperature

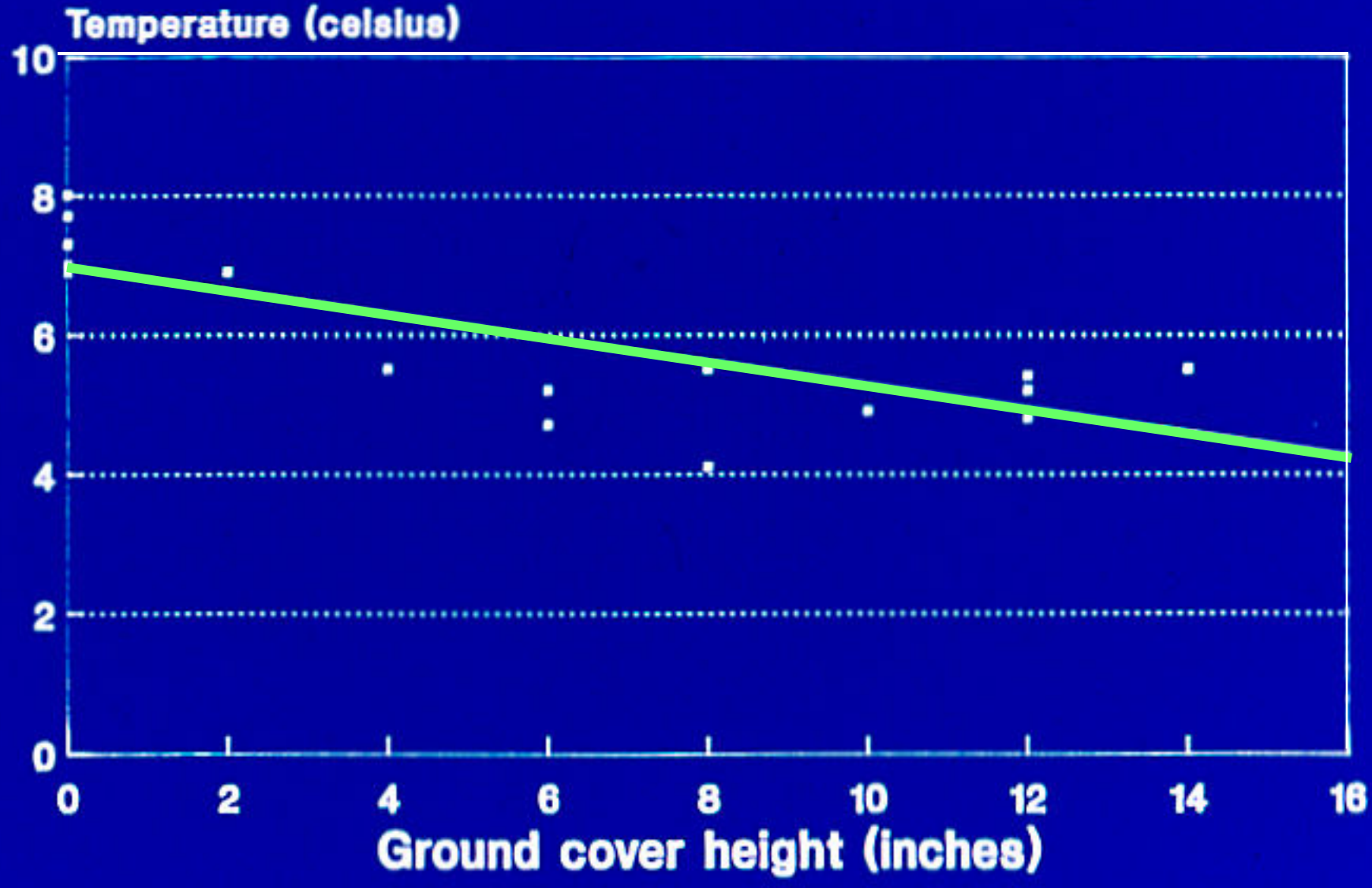



Ground
Cover

Ground Covers

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

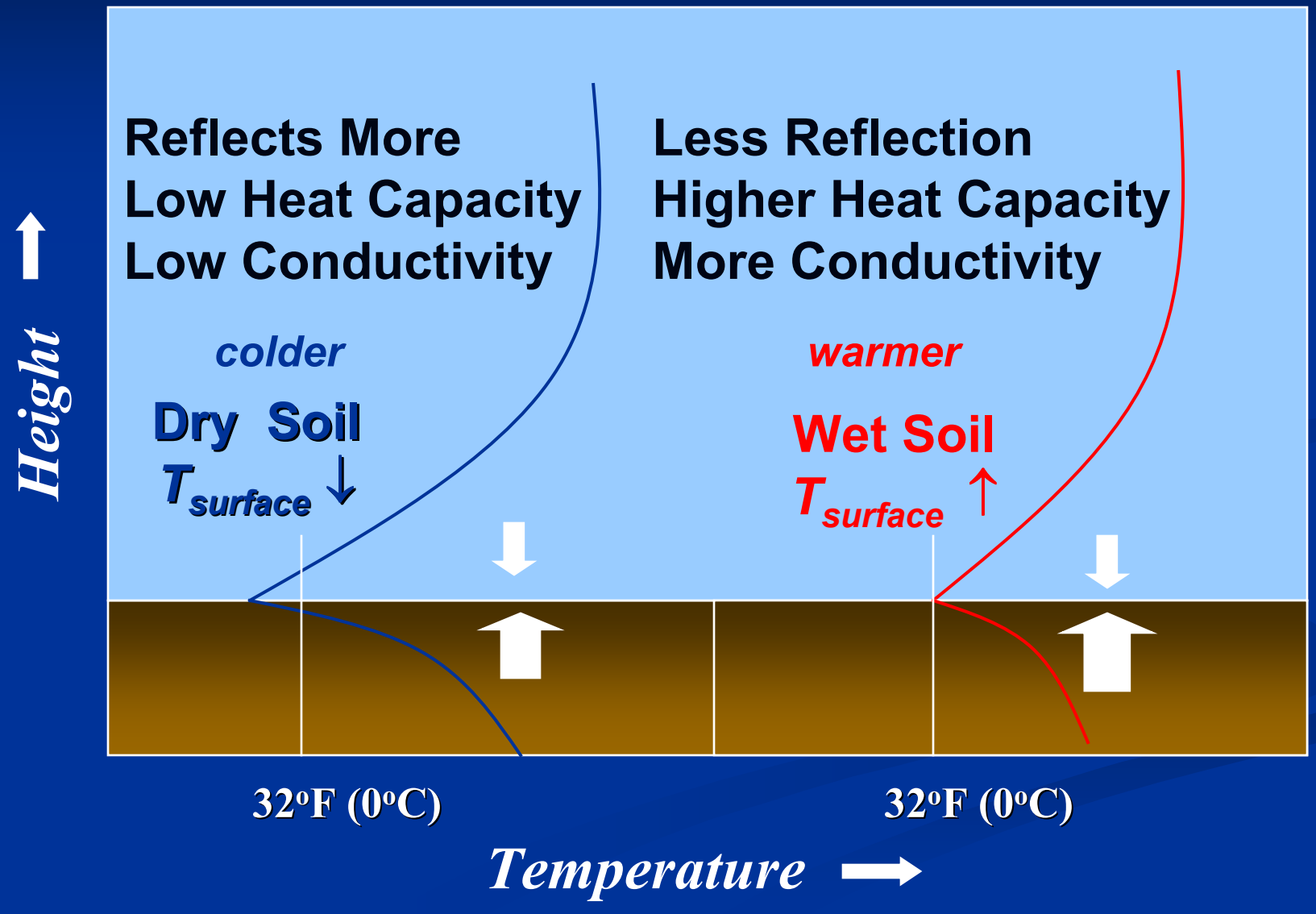
Ground Cover Temperatures
March 22, 1989



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
- Soil moisture should 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

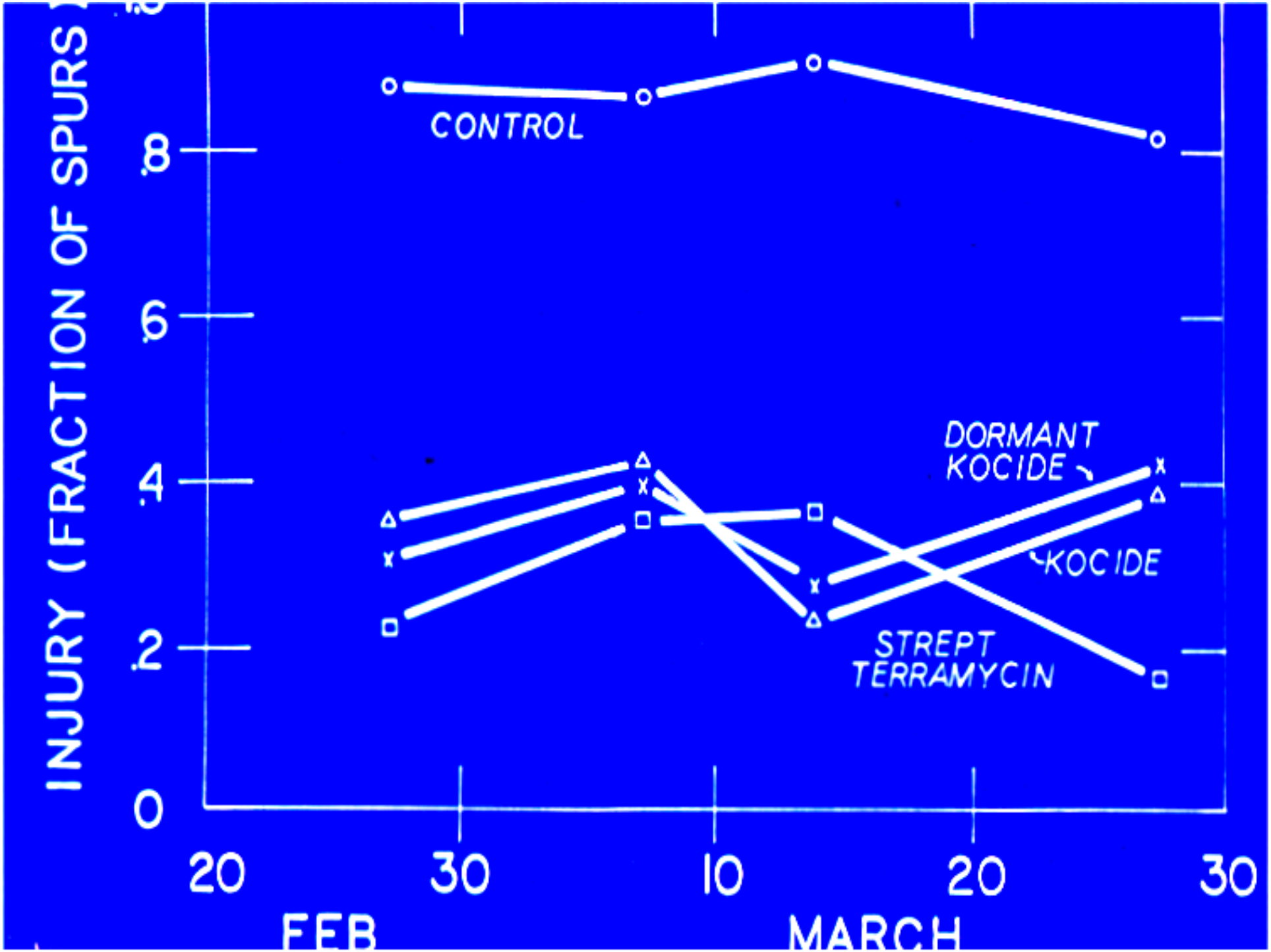

Cornstalks were used to
wrap these young trees

Bacteria control

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

Ice Nucleation

- Water can super cool or freeze below the Melting Point (0°C or 32°F).
- In the temperature range for frost damage, bacteria cause 99% of ice nucleation.


INJURY (FRACTION OF SPURS
.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 methods of Frost Protection

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

NIGHTTIME ENERGY BALANCE

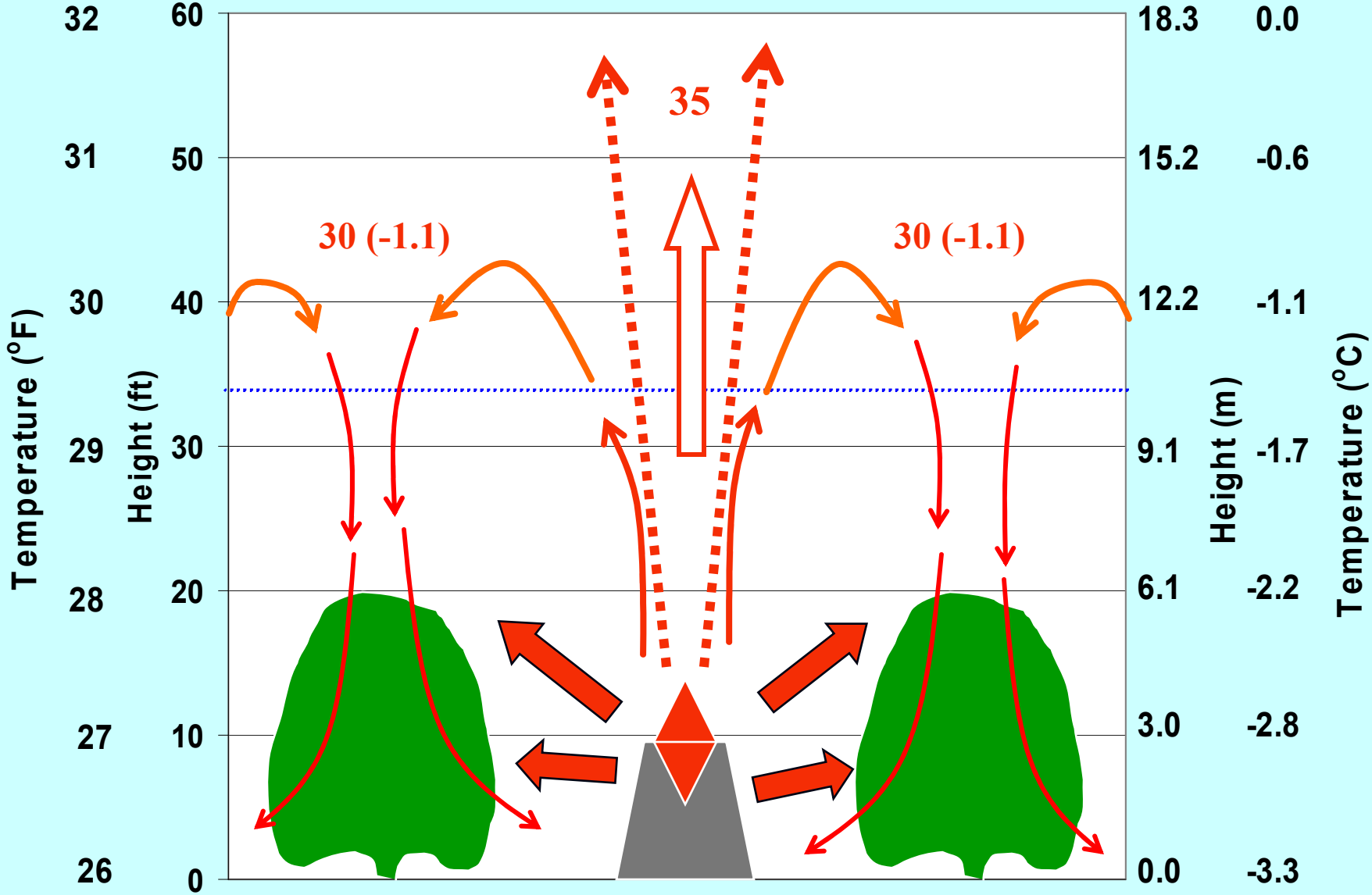
Clear sky - radiation frost

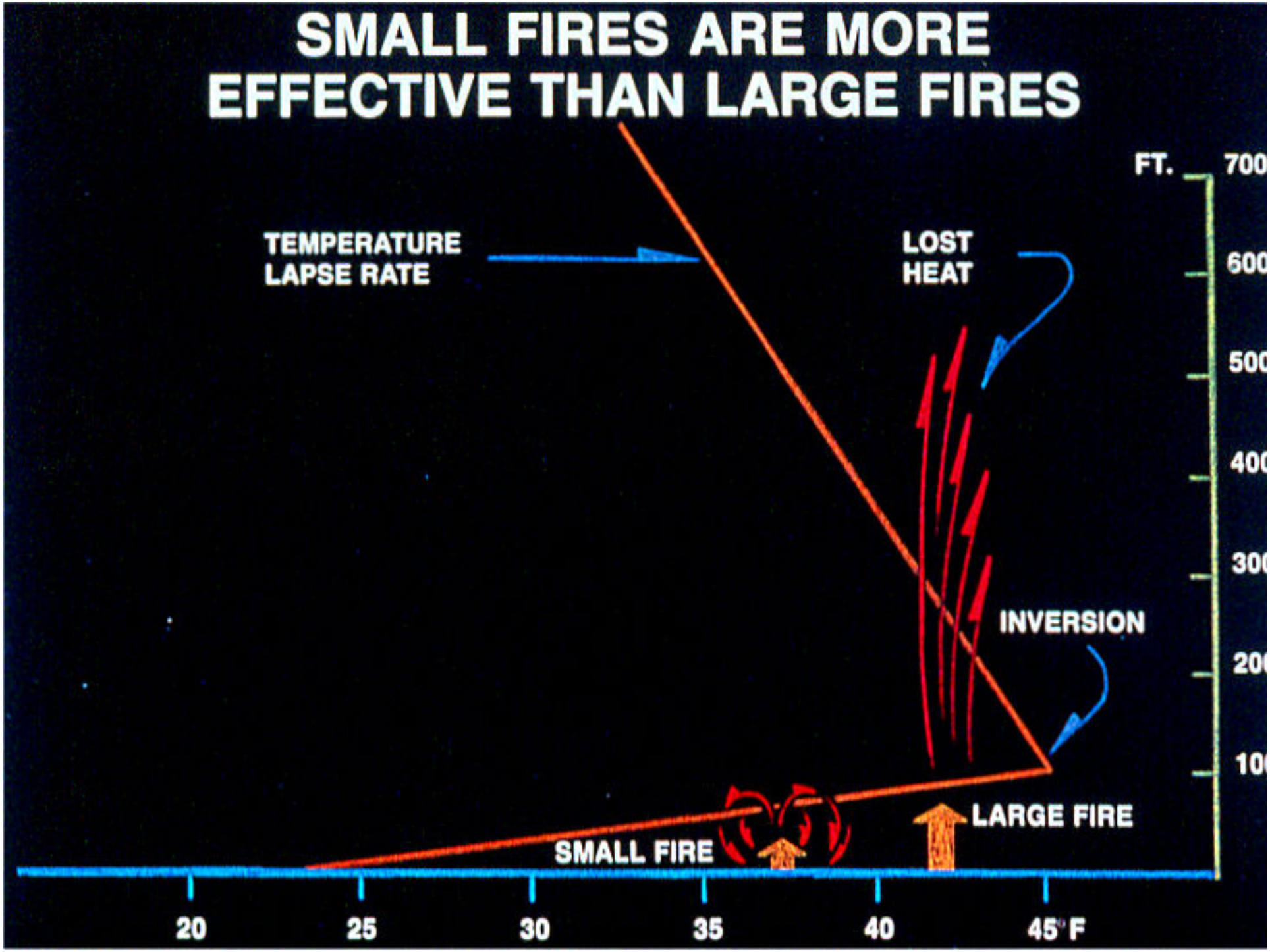
	(Btu/min)/acre	Watts/sq. meter
Energy from soil	+6446	+28
Energy from air	+8978	+39
Downward radiation	+52946	+230
Upward radiation	-72513	-315
Net energy loss	-4144	-18

Heaters

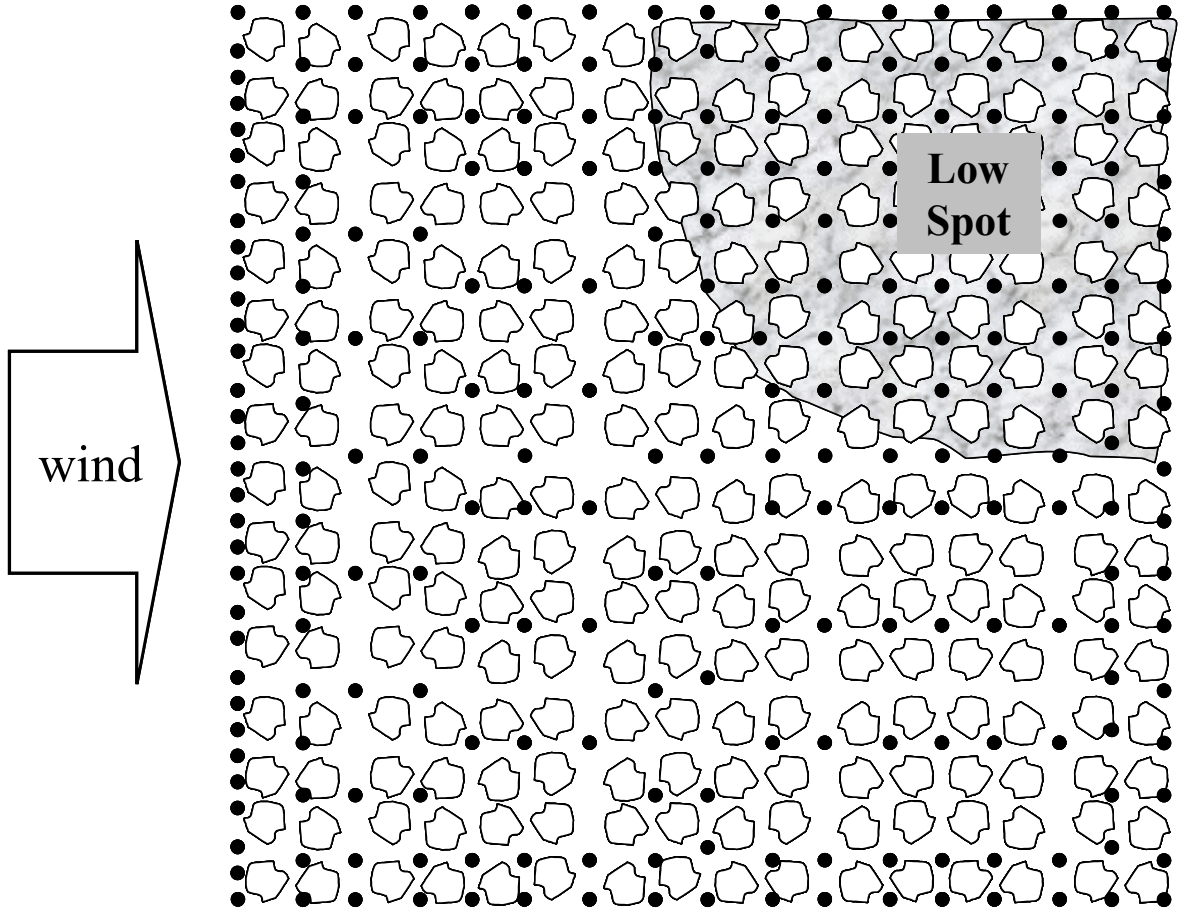
- Radiation
- Heats the air
- Convective currents

Heaters


Temperature (°F)
32
31
30
29
28
27
26
Height (ft)
60
50
40
30
20
10
0
35
30 (-1.1)
30 (-1.1)
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)


SMALL FIRES ARE MORE EFFECTIVE THAN LARGE FIRES
FT.
700
600
500
400
300
200
100
TEMPERATURE LAPSE RATE
LOST HEAT
INVERSION
LARGE FIRE
SMALL FIRE
20
25
30
35
40
45° F

Heater Placement

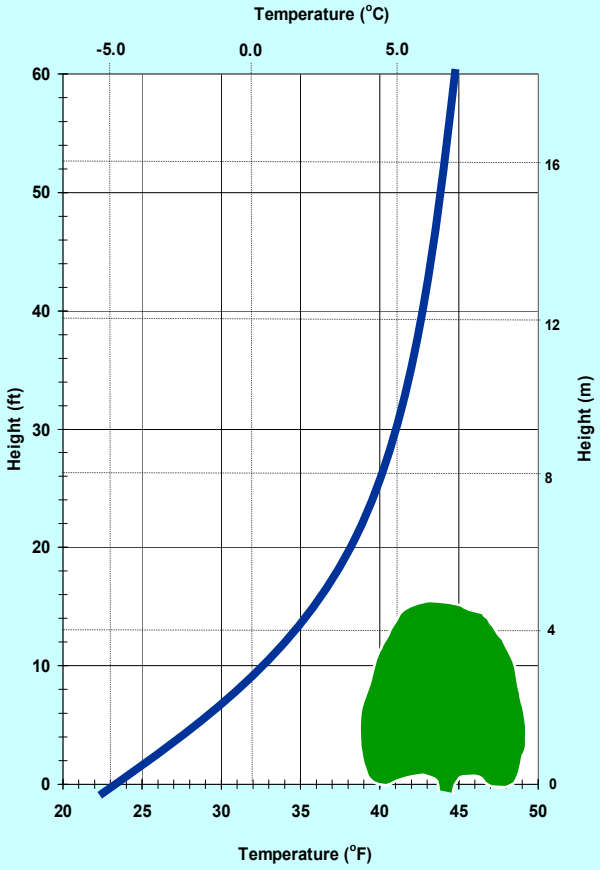


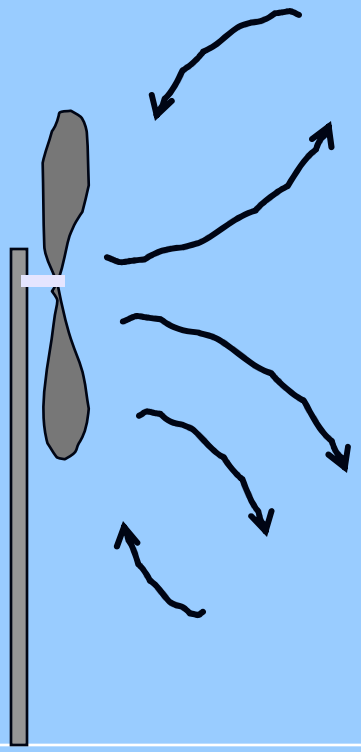
Heaters

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

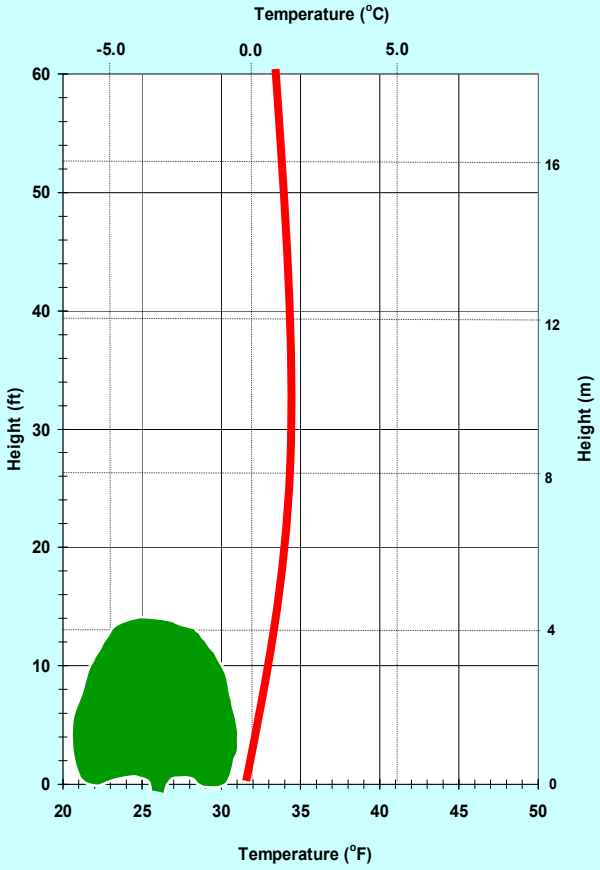
Wind Machines

No Wind Machine

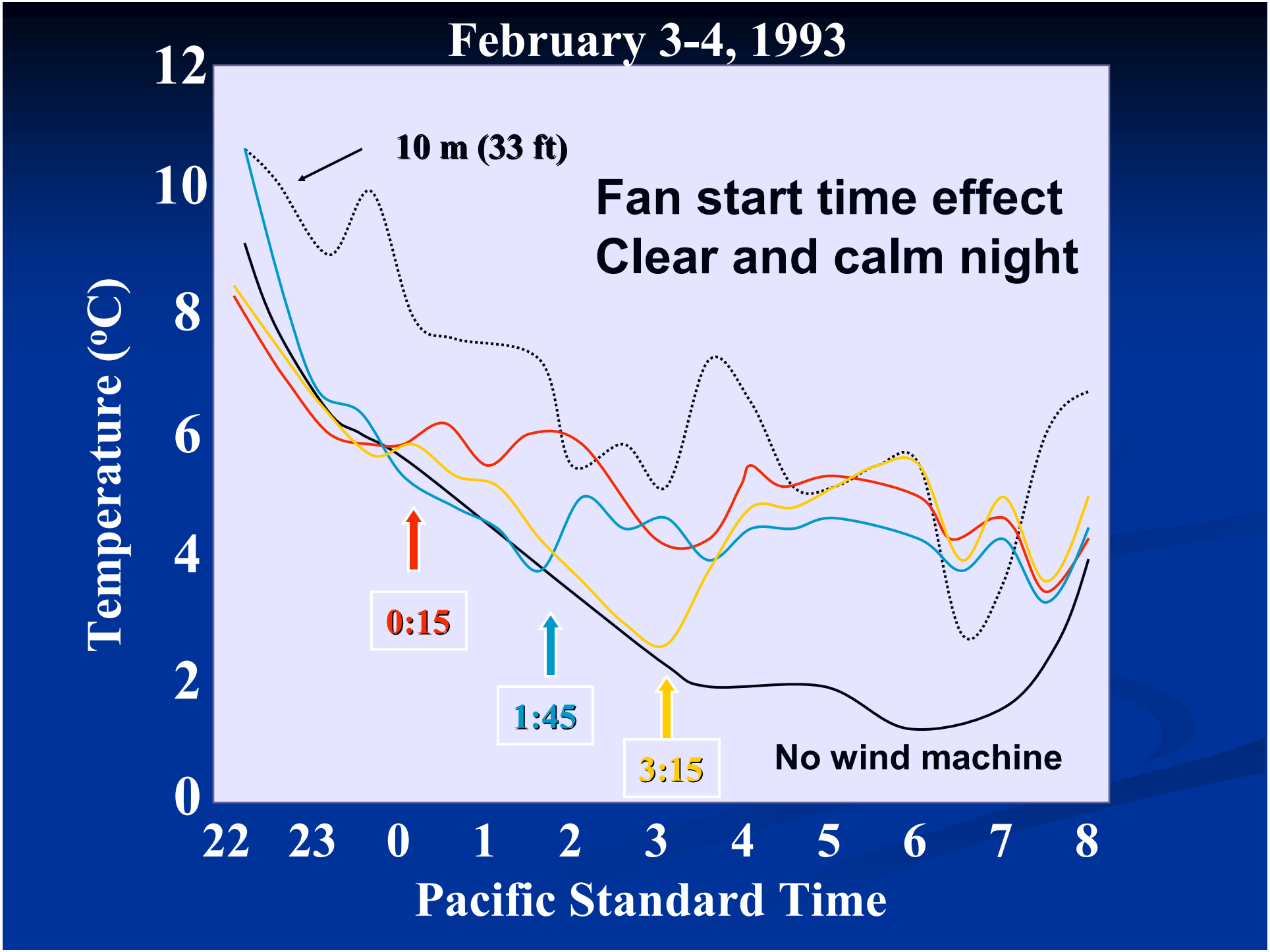


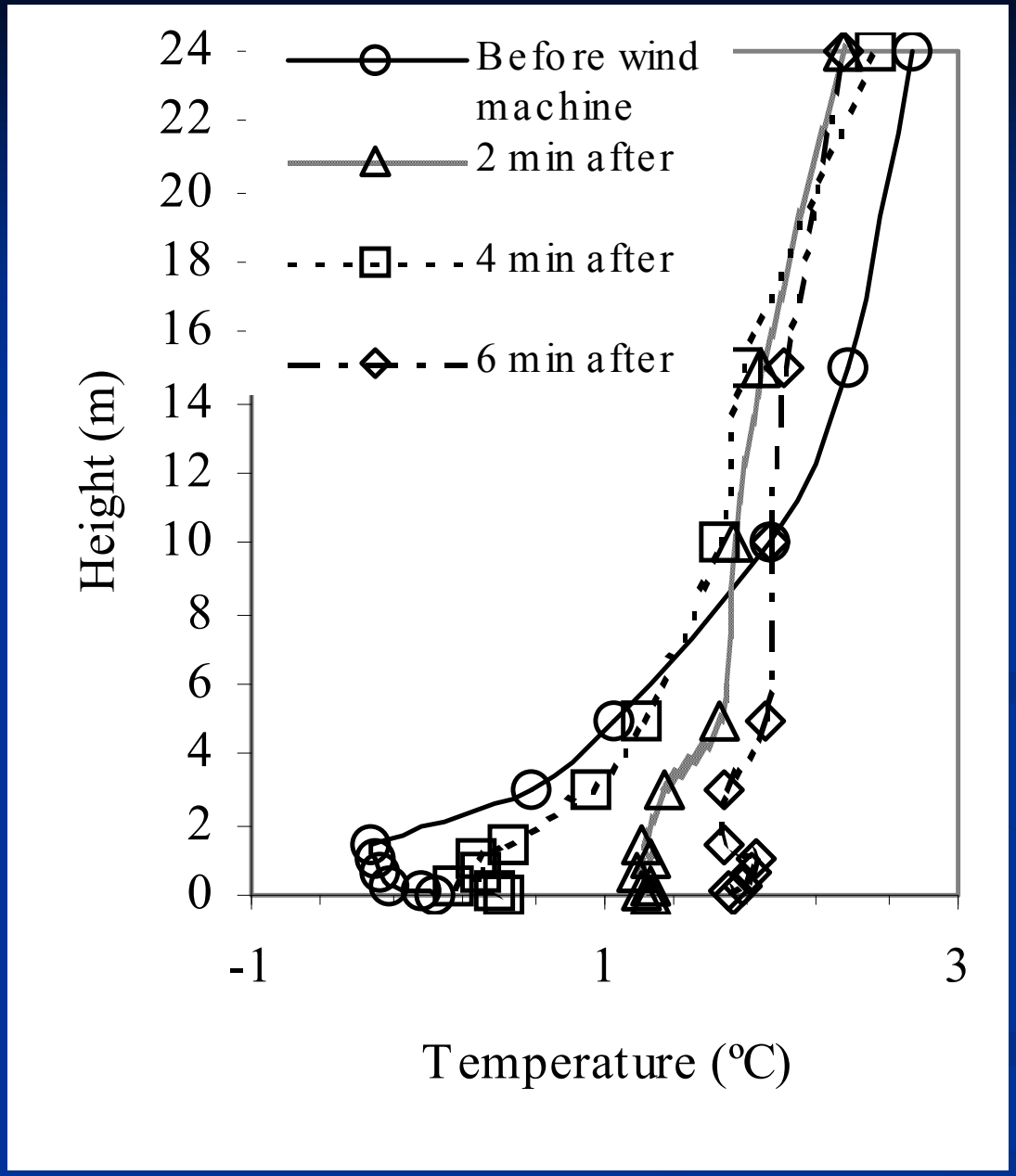


With Wind Machine



Wind machines work best in narrow valleys with strong inversions


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

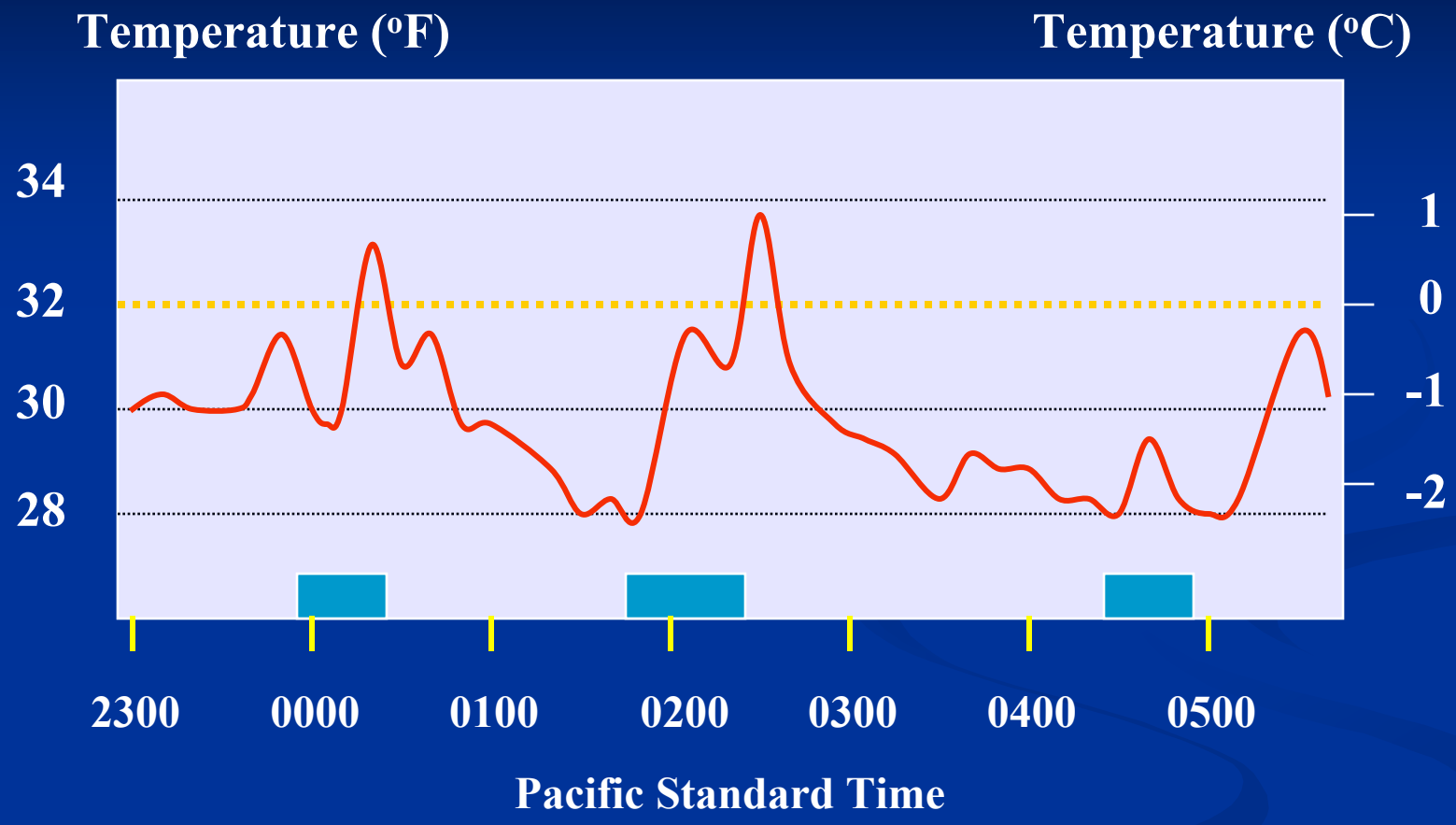


Temperature profiles (30 m from wind machine) before and after wind machine

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

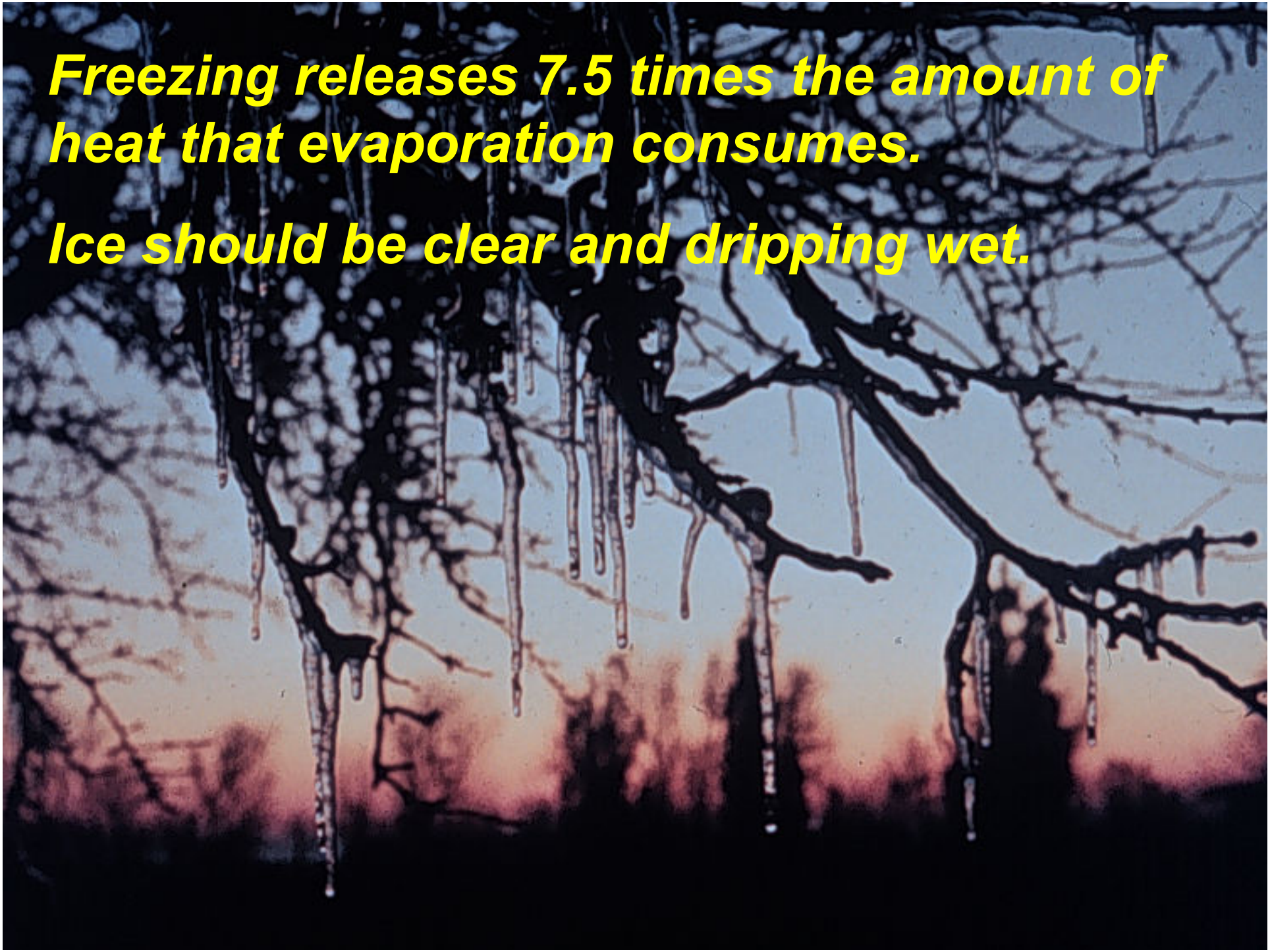
Sprinklers

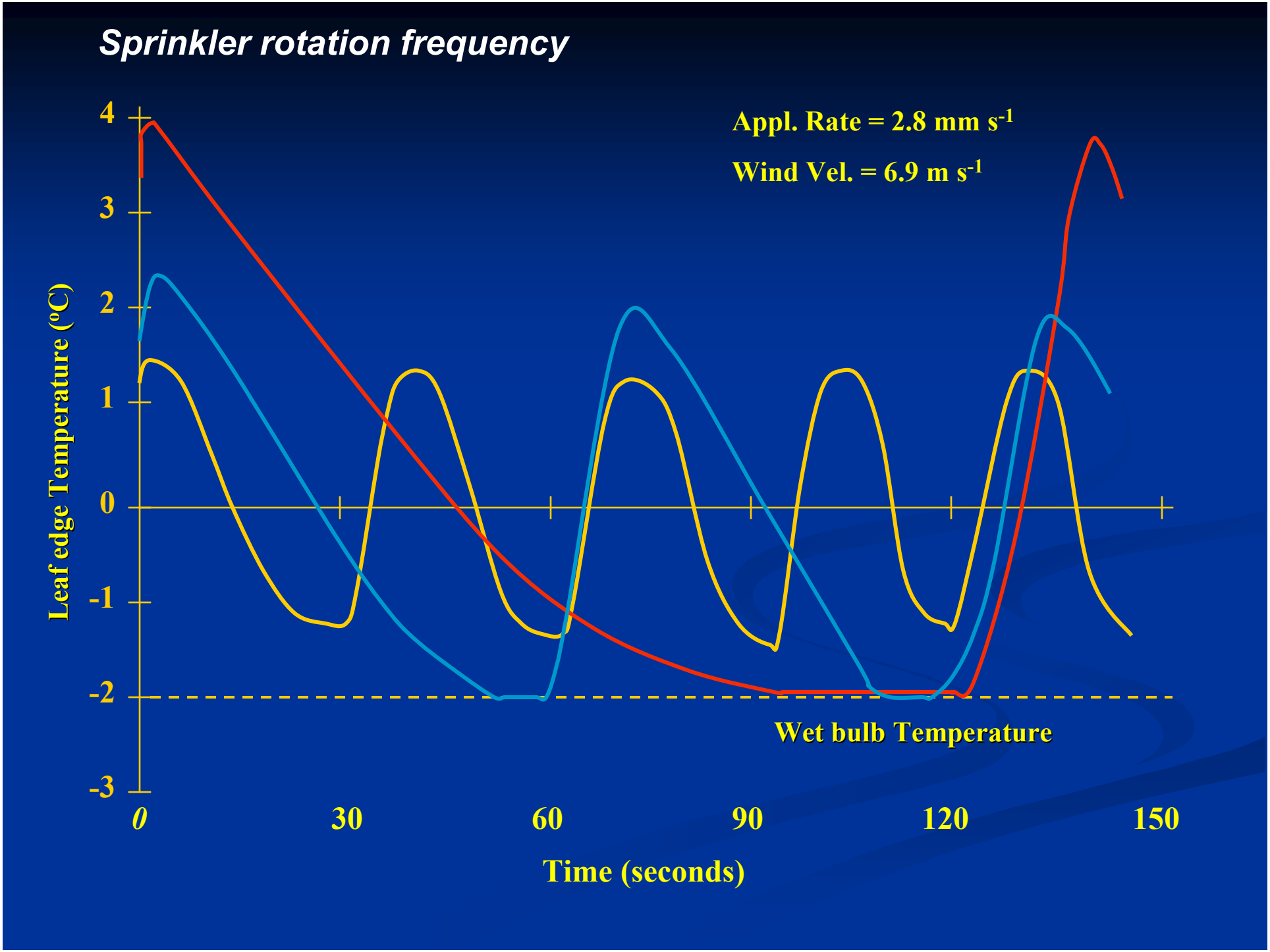
- Heat gain is from freezing water
- Must add more energy from freezing than is lost to evaporation
- Start based on Wet-bulb (critical damage temperature)

Making lots of ice can provide 4-6 degrees of protection

Latent Heat Release

Process	Calories/gm	Joules/gm
$20^{o}C$ to $0^{o}C$ $68^{o}F$ to $32^{o}F$	20	84
Freezing at $0^{o}C$ ($32^{o}F$)	80	335
Evaporation at $0^{o}C$ ($32^{o}F$)	-597	-2500


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


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

Application Rates for Freeze Protection of Tall Crops

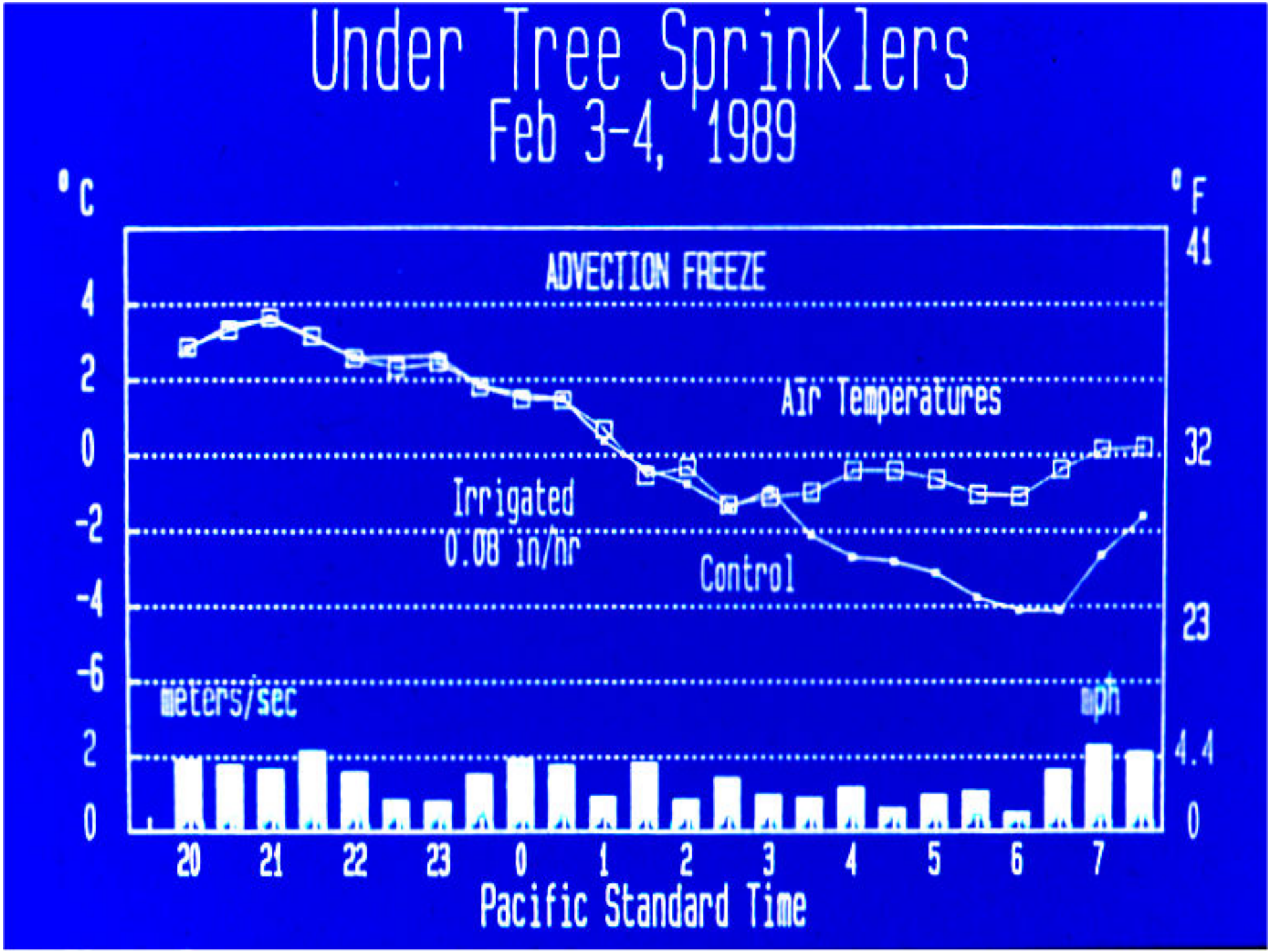
Temperature	Wind Speed	30 s rotation	60 s rotation
°F	mph	in/hr	in/hr
29	0.0-1.1	0.08	0.10
26	0.0-1.1	0.10	0.13
23	0.0-1.1	0.15	0.17
29	2.0-3.0	0.10	0.12
26	2.0-3.0	0.13	0.15
23	2.0-3.0	0.18	0.20
Temperature	**Wind Speed**	**30 s rotation**	**60 s rotation**
°F	mph	gpm/A	gpm/A
29	0.0-1.1	36	45
26	0.0-1.1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

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

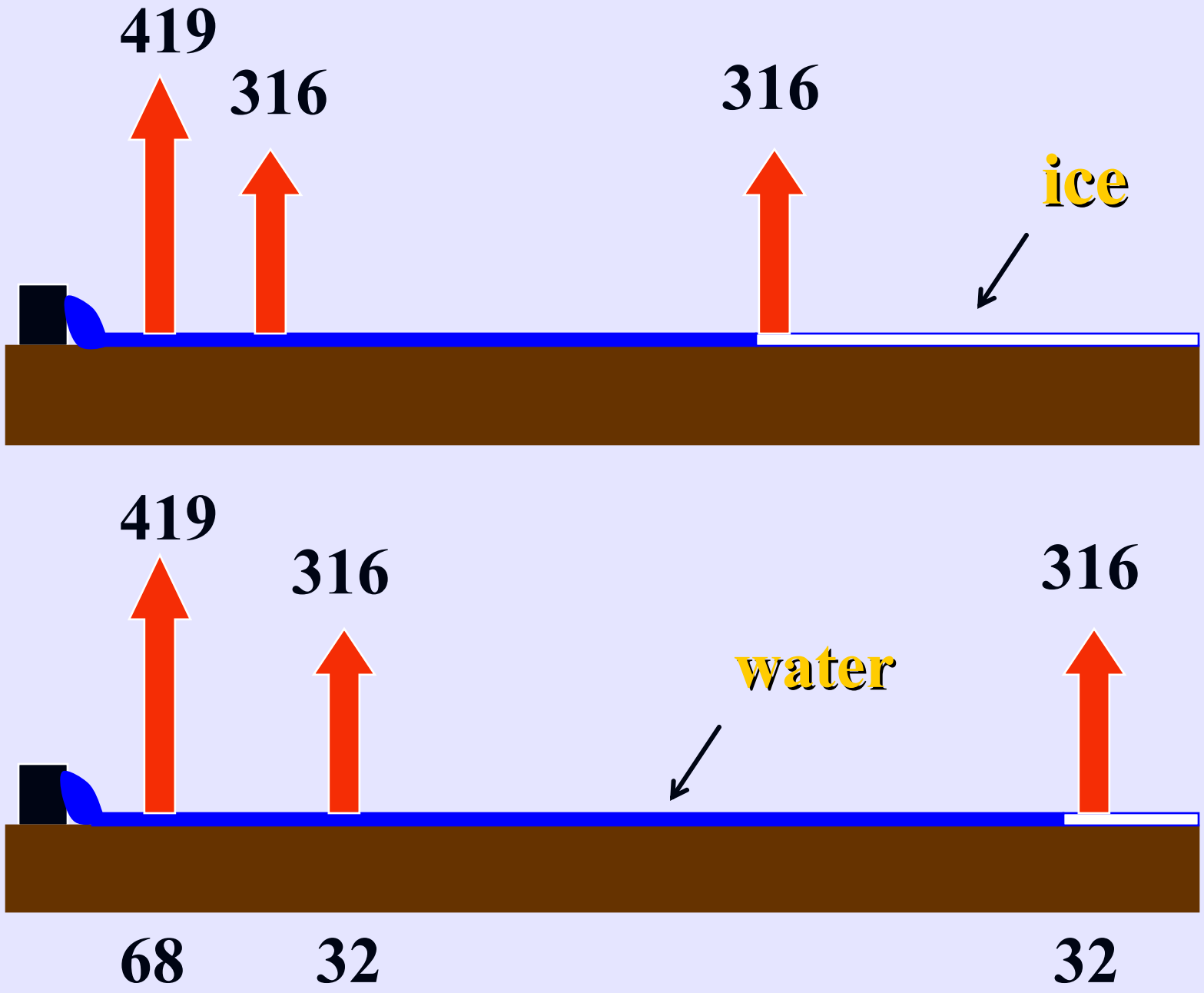
When to turn off sprinklers?

- 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
°C
°F
ADVECTION FREEZE
Air Temperatures
Irrigated
0.08 in/hr
Control
meters/sec
mph
4
2
0
-2
-4
-6
2
0
41
32
23
4.4
0
20
21
22
23
0
1
2
3
4
5
6
7
Pacific Standard Time

Surface irrigation

- Either flood or furrow
- Heat is released as the water cools


419
316
316
ice
419
316
316
water
68
32
32

Surface irrigation

- Concentrate the flooding in furrows near the tree skirts
- 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

Today's presentation was made possible through my work with Dr. Richard Snyder, Extension Bio meteorologist. For more information visit his web site:

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