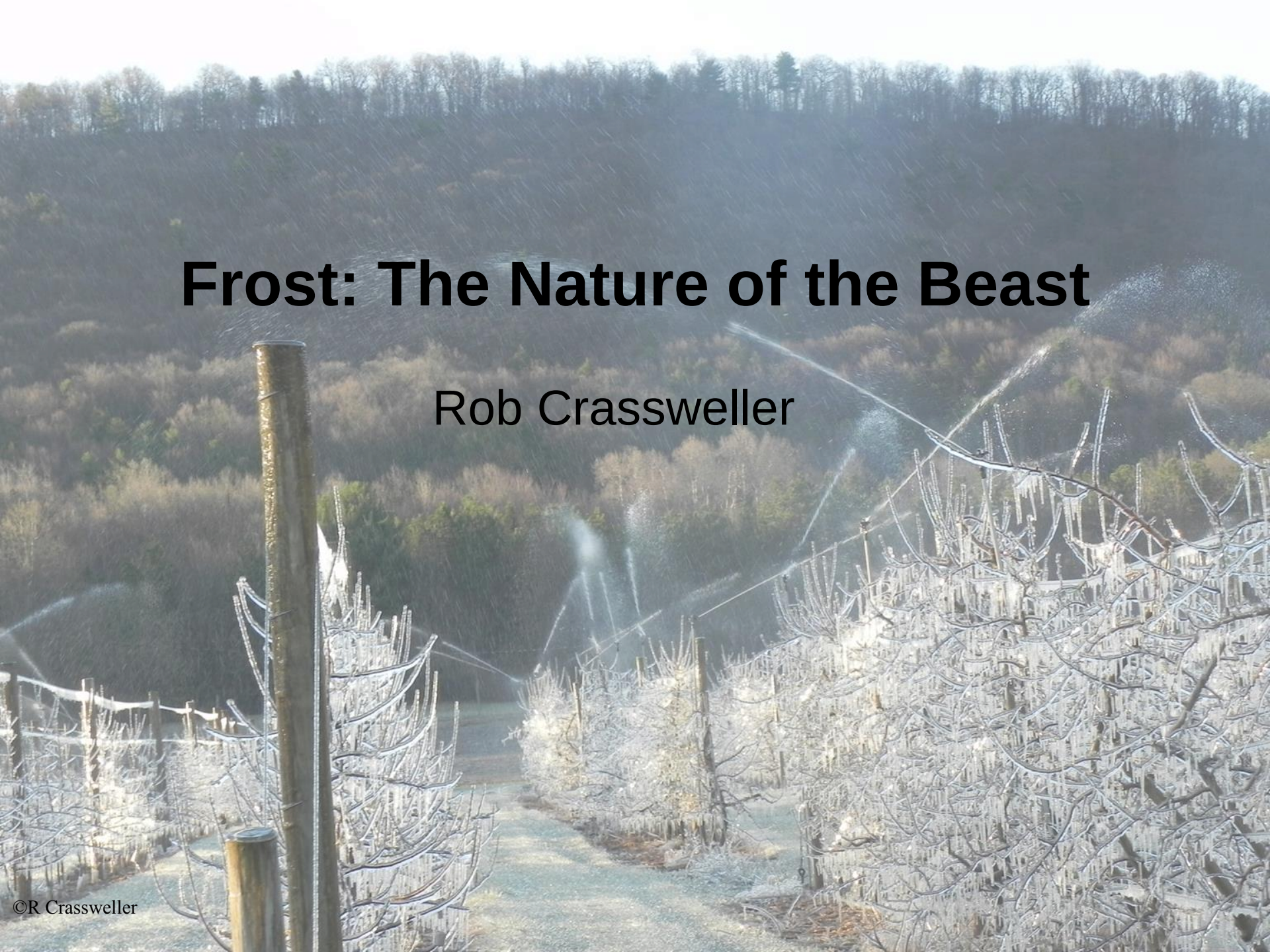
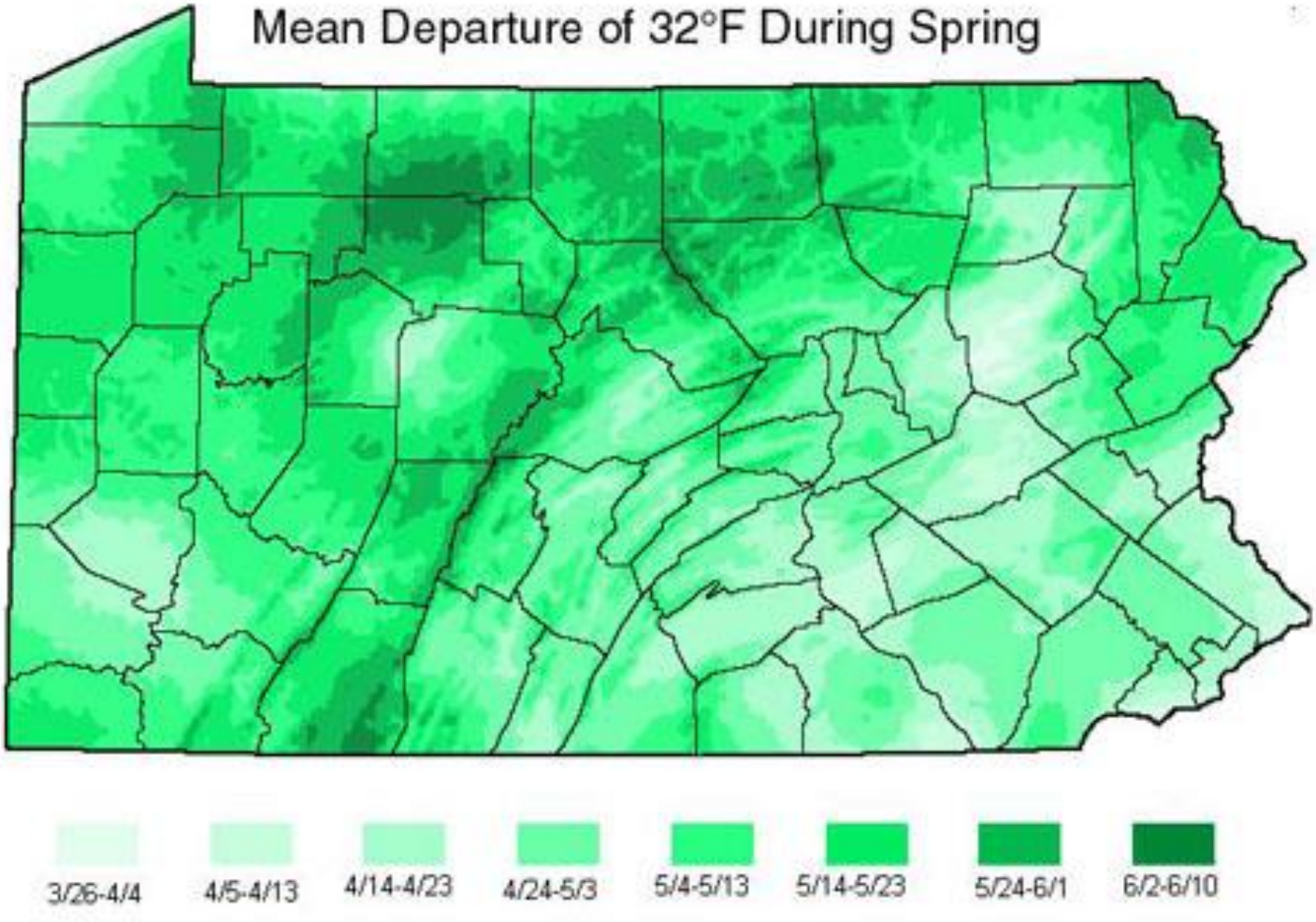


Frost: The Nature of the Beast

Rob Crassweller



Critical Temperatures

Table 1-25. Critical temperatures for various fruits.

Stage of development	10% kill (°F)	90% kill (°F)
Apples [a]		
Silver tip	15	2
Green tip	18	10
1/2-inch green	23	15
Tight cluster	27	21
First pink	28	24
Full pink	28	25
First bloom	28	25
Full bloom	28	25
Post bloom	28	25
Peaches		
First swelling	18	1
Calyx green	21	5
Calyx red	23	9
First pink	25	15
First bloom	26	21
Full bloom	27	24
Post bloom	28	25

Stage of development	10% kill (°F)	90% kill (°F)
Pears [b]		
Scales separating	15	0
Blossom buds exposed	20	6
Tight cluster	24	15
First white	25	19
Full white	26	22
First bloom	27	23
Full bloom	28	24
Post bloom	28	24
Sweet cherries		
First swelling	17	5
Side green	22	9
Green tip	25	14
Tight cluster	26	17
Open cluster	27	21
First white	27	24
First bloom	28	25
Full bloom	28	25
Post bloom	28	25

Stage of development	10% kill (°F)	90% kill (°F)
Apricots		
First swelling	15	-
Tip separates	20	0
Red calyx	22	9
First white	24	14
First bloom	25	19
Full bloom	27	22
In the shuck	27	24
Green fruit	28	25

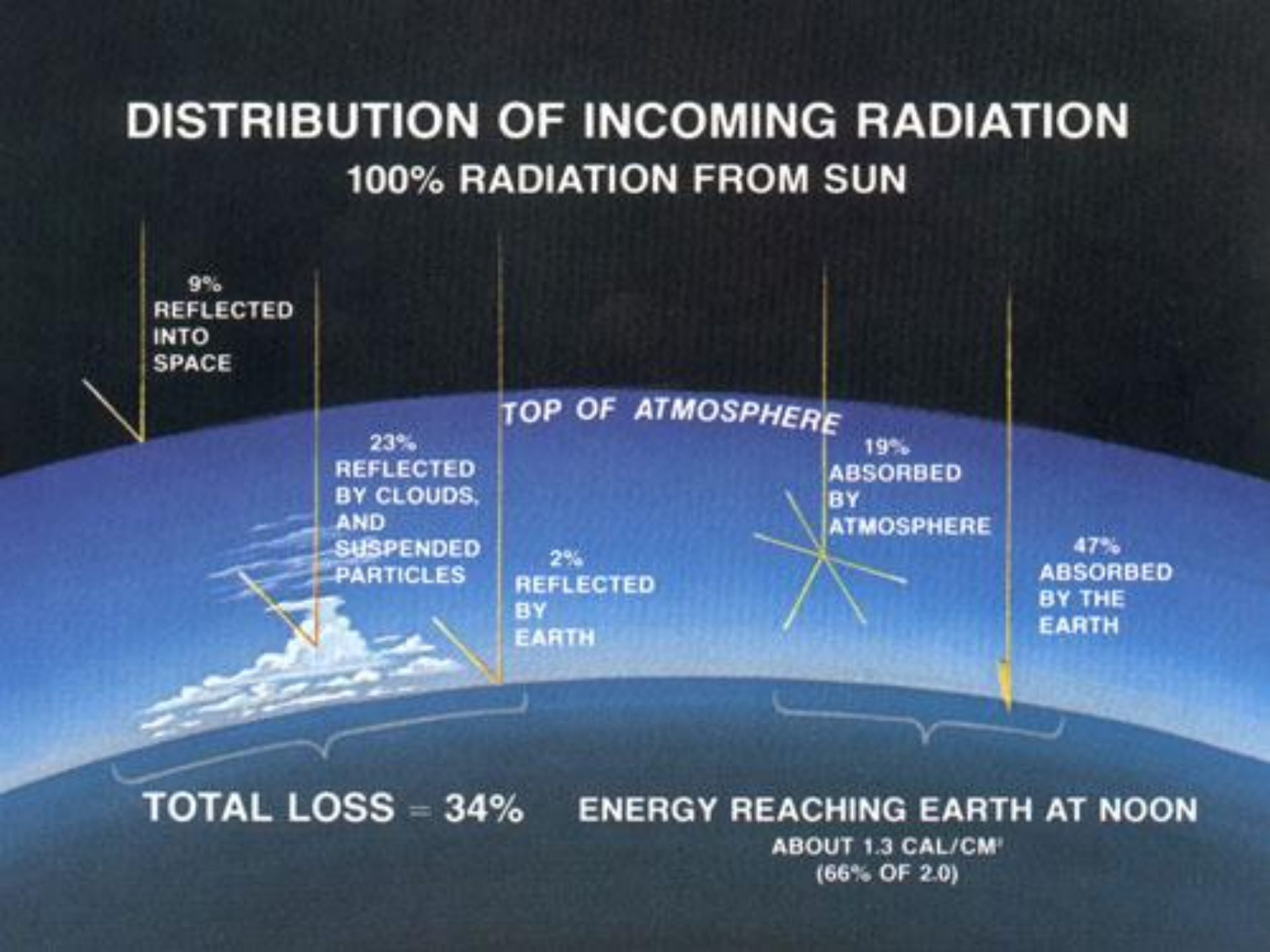
[a] *For Red Delicious. Golden Delicious and Winesap are approximately 1 degree hardier. Rome Beauty is 2 degrees hardier, except after petal fall when all cultivars are equally tender.*

[b] *For Bartlett. D'Anjou is similar but may bloom earlier and therefore may be more tender than Bartlett at the same date.*

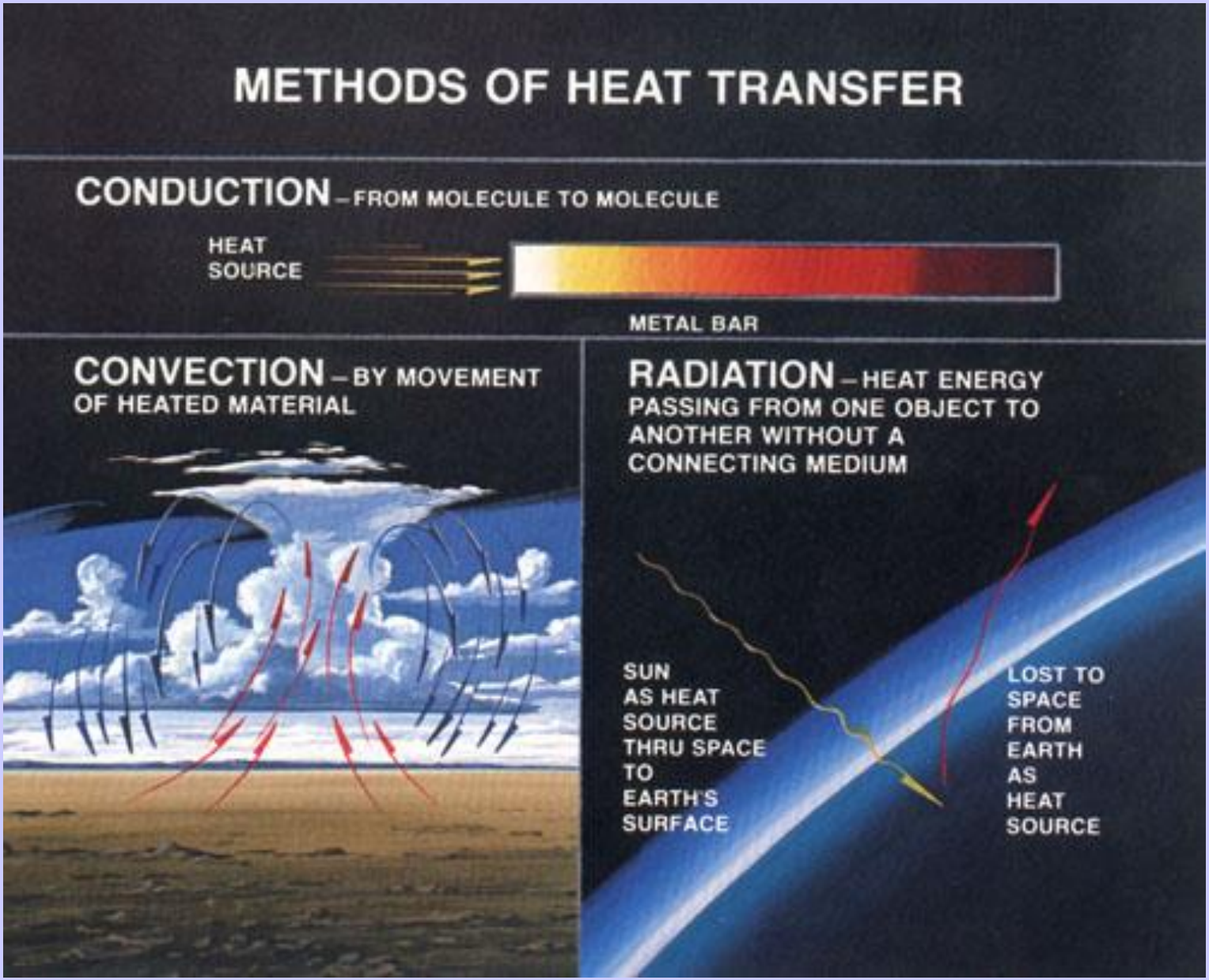
Adapted from *1989 Spray Guide for Tree Fruits in Eastern Washington*. Bulletin EBO419. E.H. Beers, coordinator.

Frost Damage to Flower Buds

- Depends upon
  - Stage of flowering – king bloom vs. pink
  - Wind
  - Humidity
  - Cultivar
  - Tree Vigor
  - Weather Prior to Frost
  - Rate of Thawing


DISTRIBUTION OF INCOMING RADIATION
100% RADIATION FROM SUN
9% REFLECTED INTO SPACE
TOP OF ATMOSPHERE
23% REFLECTED BY CLOUDS, AND SUSPENDED PARTICLES
2% REFLECTED BY EARTH
19% ABSORBED BY ATMOSPHERE
47% ABSORBED BY THE EARTH
TOTAL LOSS = 34%
ENERGY REACHING EARTH AT NOON
ABOUT 1.3 CAL/CM²
(66% OF 2.0)

Methods of Heat Transfer



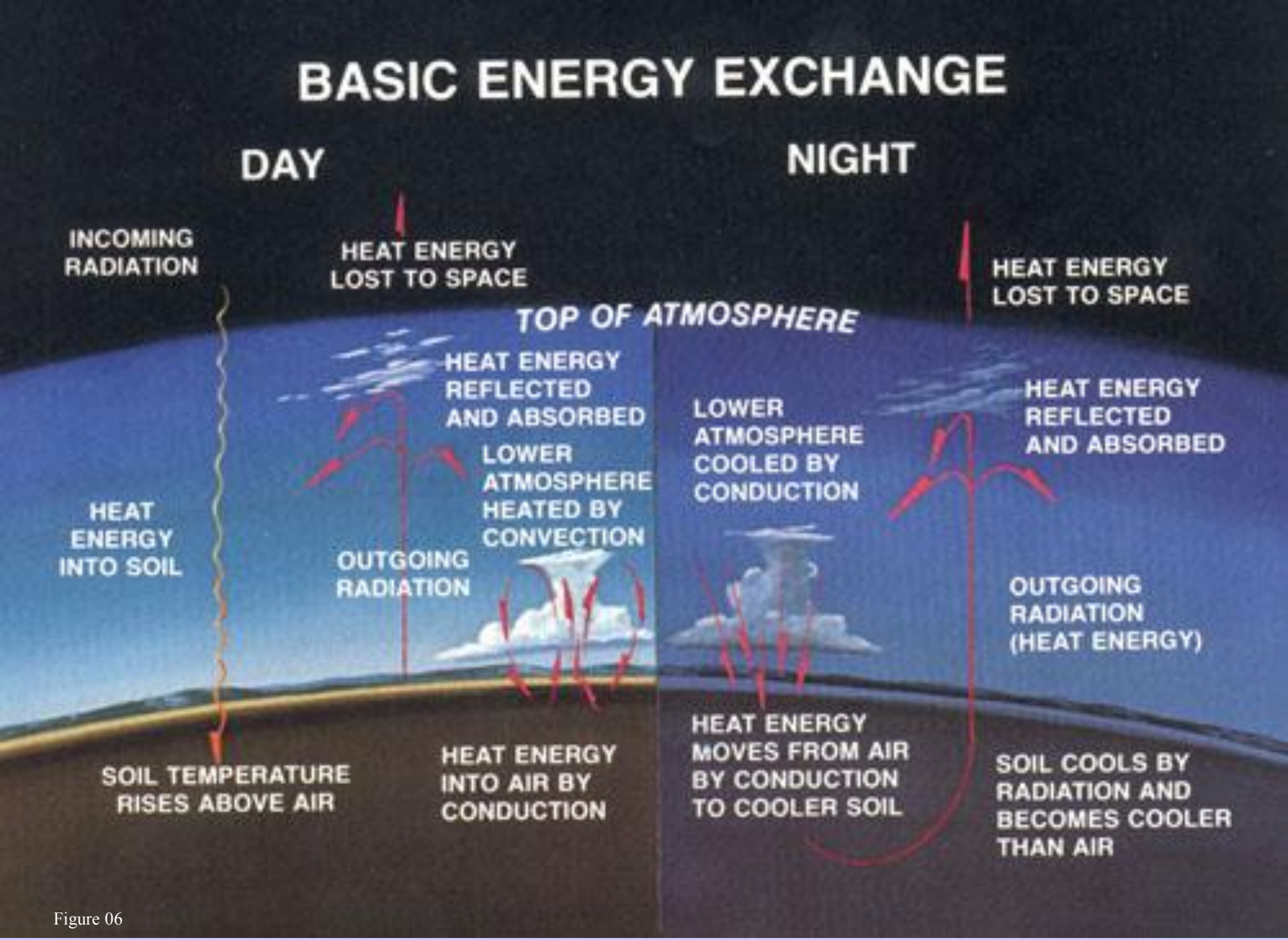

BASIC ENERGY EXCHANGE
DAY
NIGHT
INCOMING RADIATION
HEAT ENERGY LOST TO SPACE
TOP OF ATMOSPHERE
HEAT ENERGY LOST TO SPACE
HEAT ENERGY REFLECTED AND ABSORBED
LOWER ATMOSPHERE HEATED BY CONVECTION
LOWER ATMOSPHERE COOLED BY CONDUCTION
HEAT ENERGY REFLECTED AND ABSORBED
HEAT ENERGY INTO SOIL
OUTGOING RADIATION
OUTGOING RADIATION (HEAT ENERGY)
SOIL TEMPERATURE RISES ABOVE AIR
HEAT ENERGY INTO AIR BY CONDUCTION
HEAT ENERGY MOVES FROM AIR BY CONDUCTION TO COOLER SOIL
SOIL COOLS BY RADIATION AND BECOMES COOLER THAN AIR

Figure 06

Types of Freezes

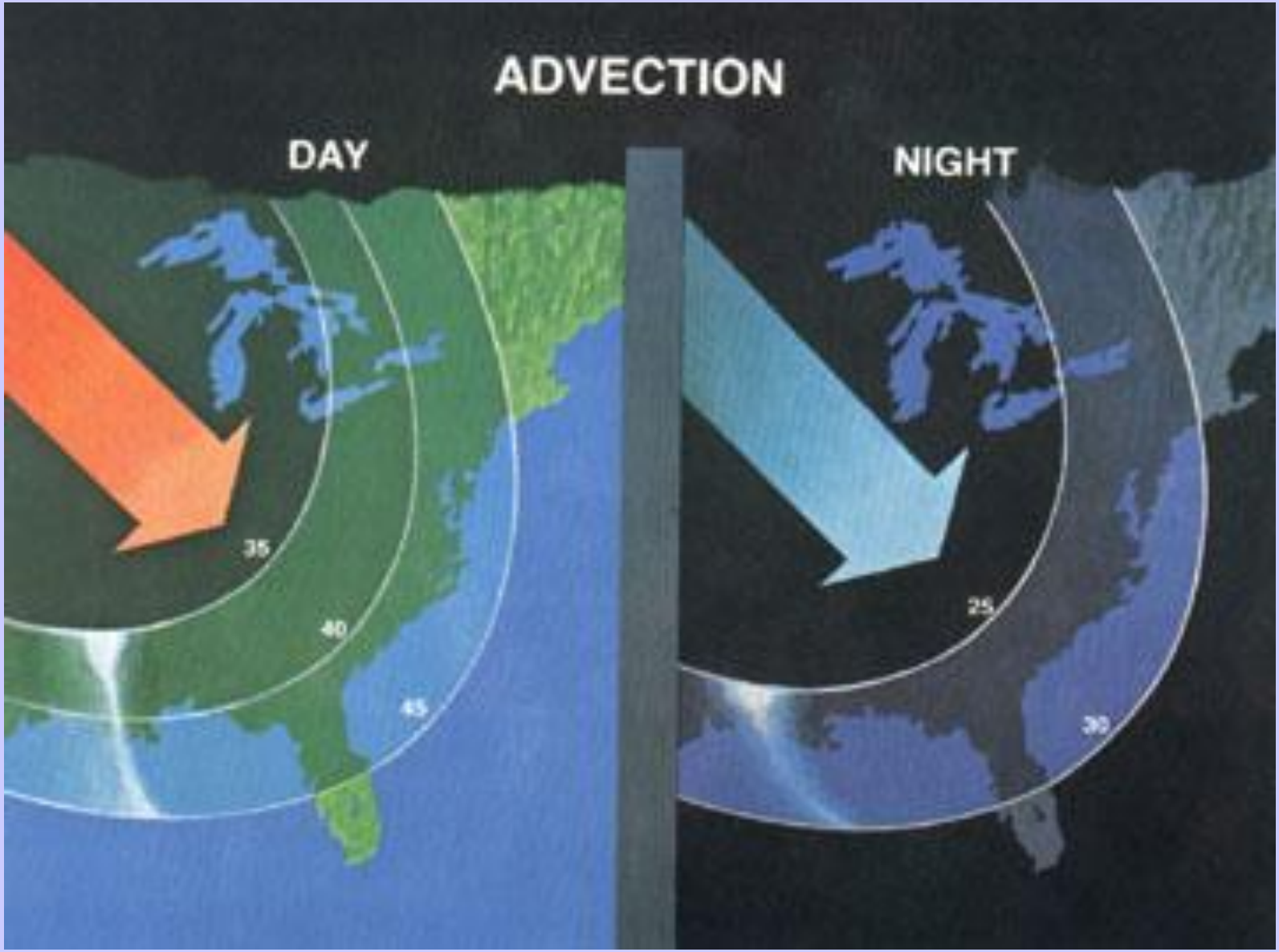
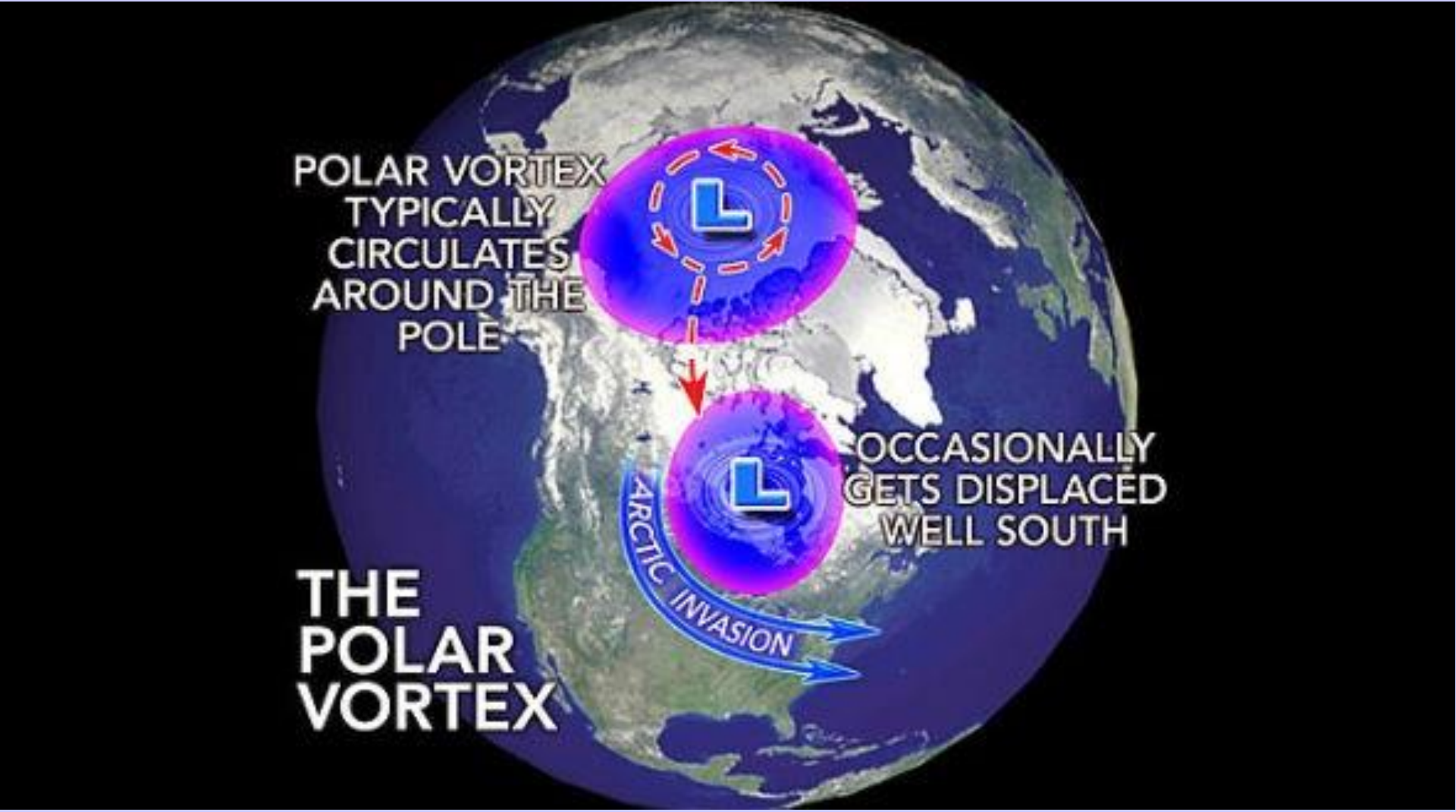


Figure 01, Valli, V. J. 1971. Basic principles of freeze occurrence and the prevention of freeze damage to crops.



Large low pressure pocket of cold air sitting over the polar regions. Large pocket of high pressure can push the ‘polar vortex’ down into Canada and northern U.S.

Types of Freezes

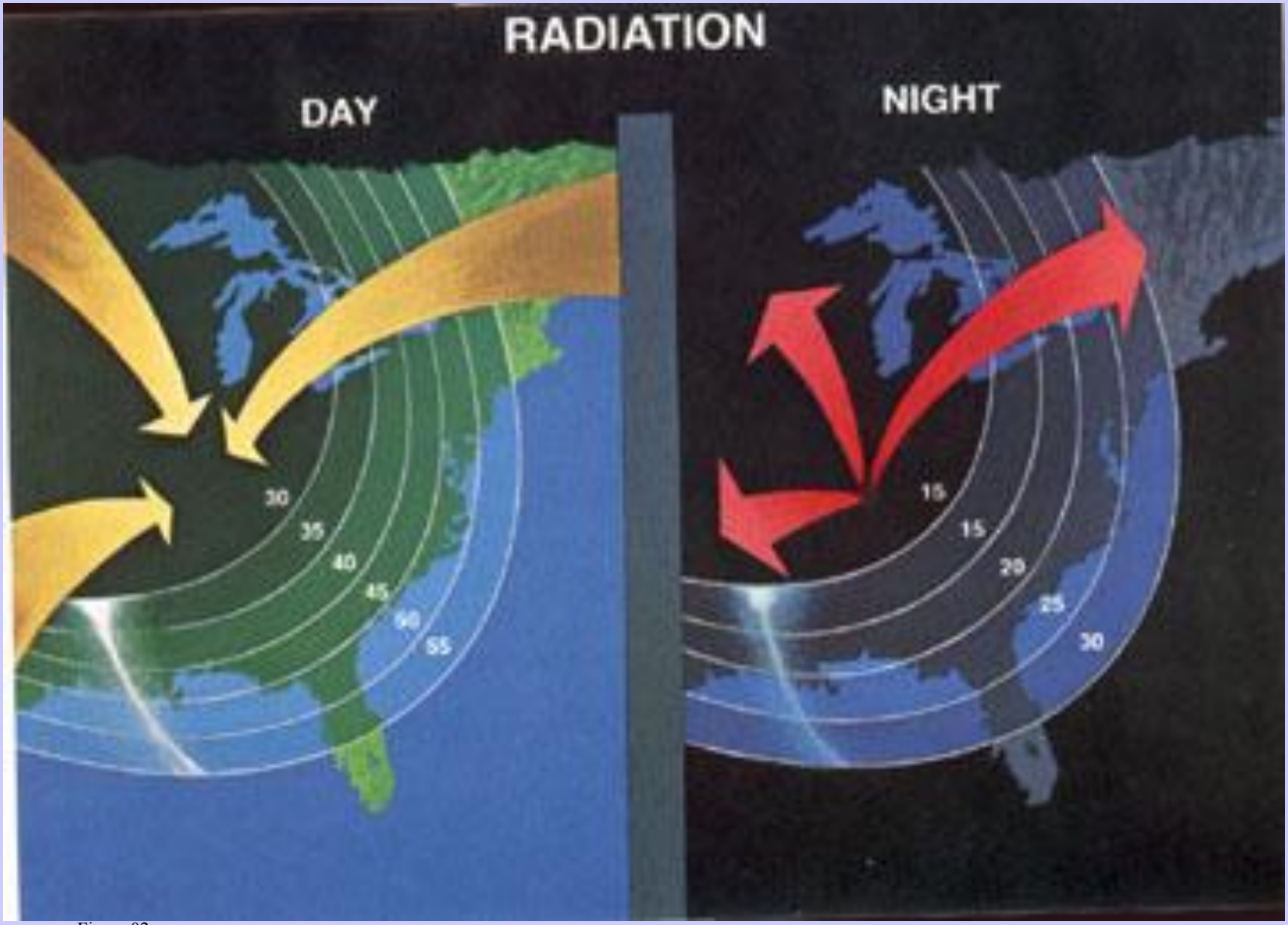


Figure 02

Air Layers

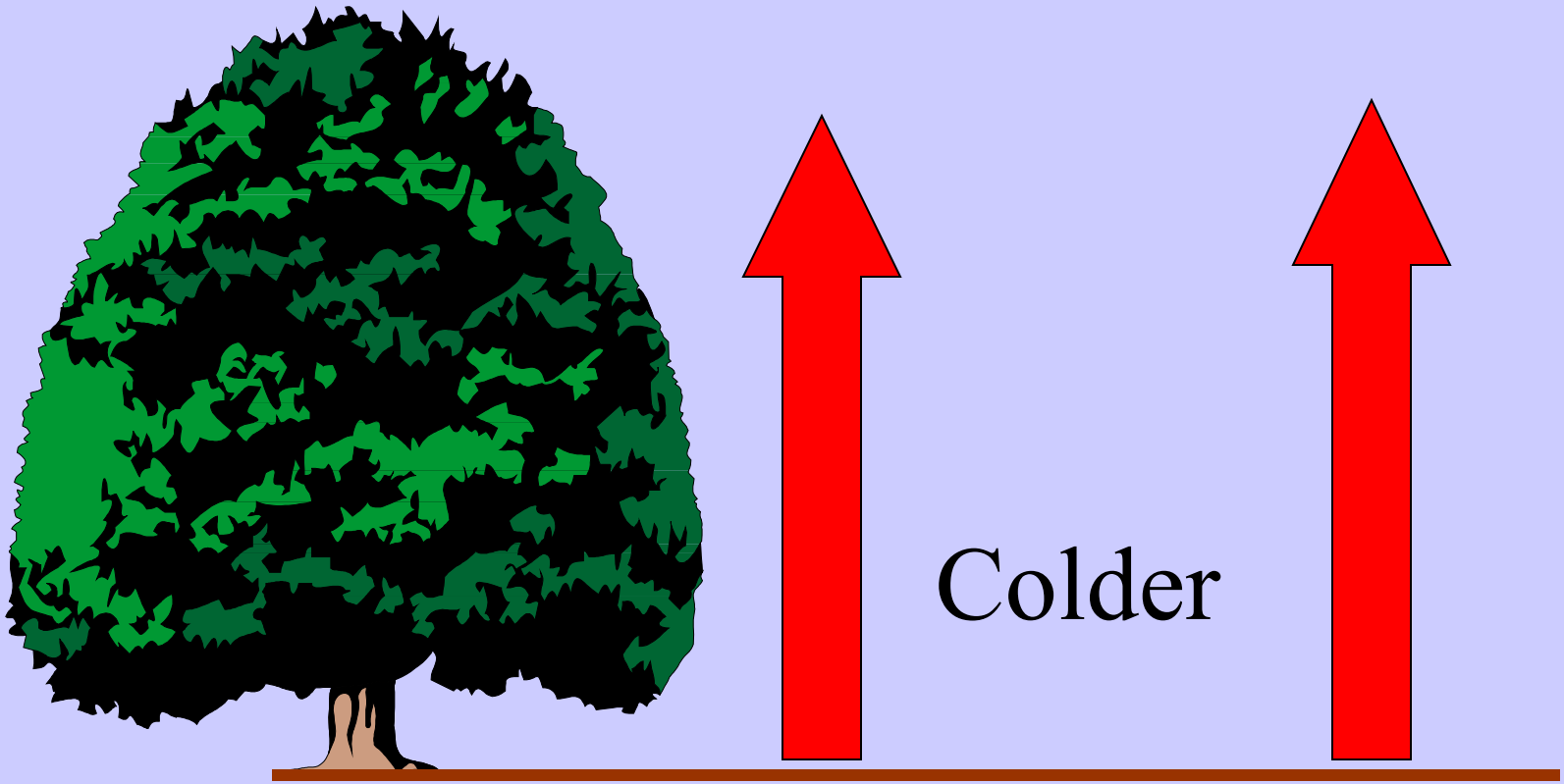
Daytime

Colder

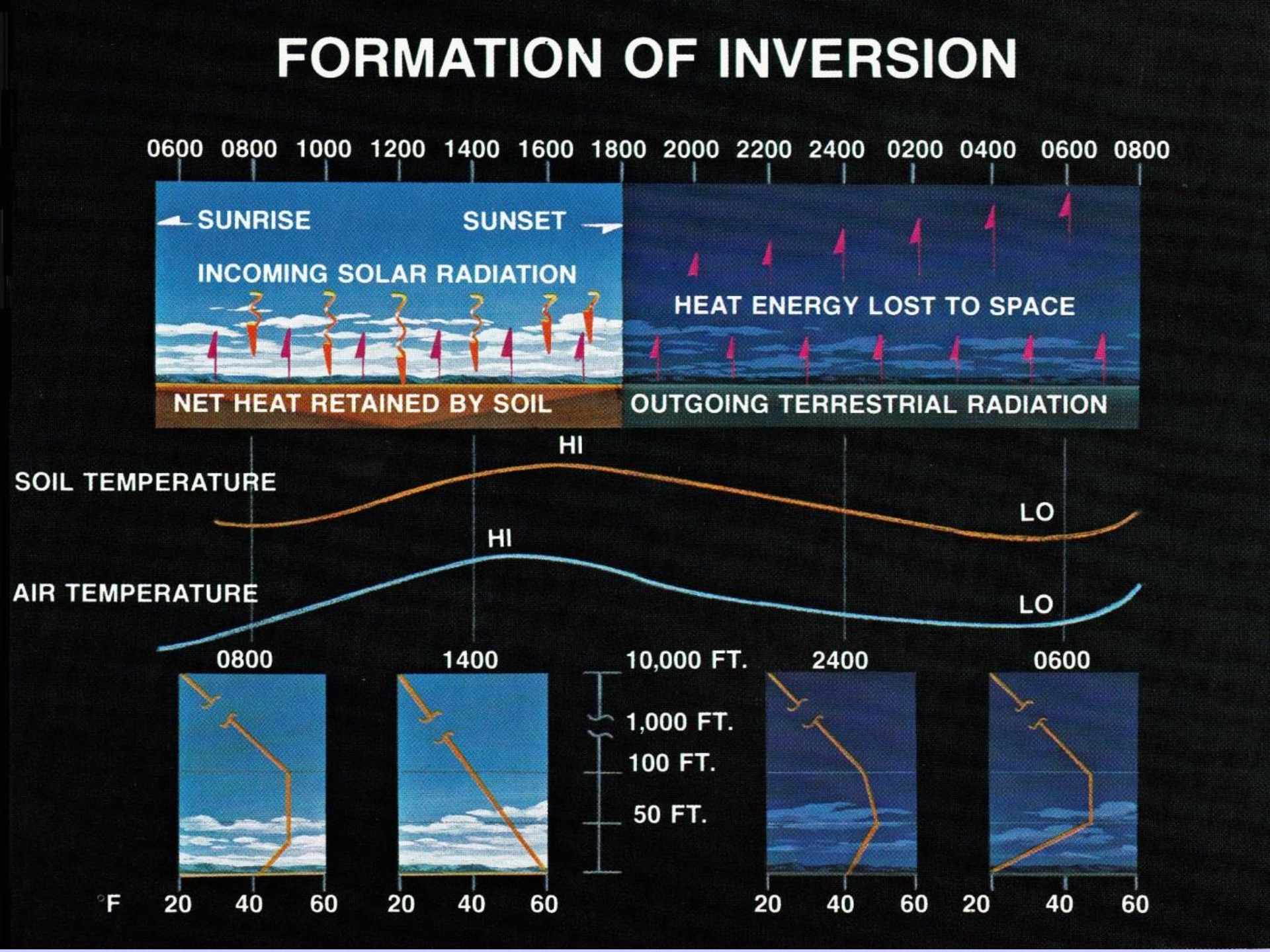
Warmer

Air Layers

Nighttime



FORMATION OF INVERSION



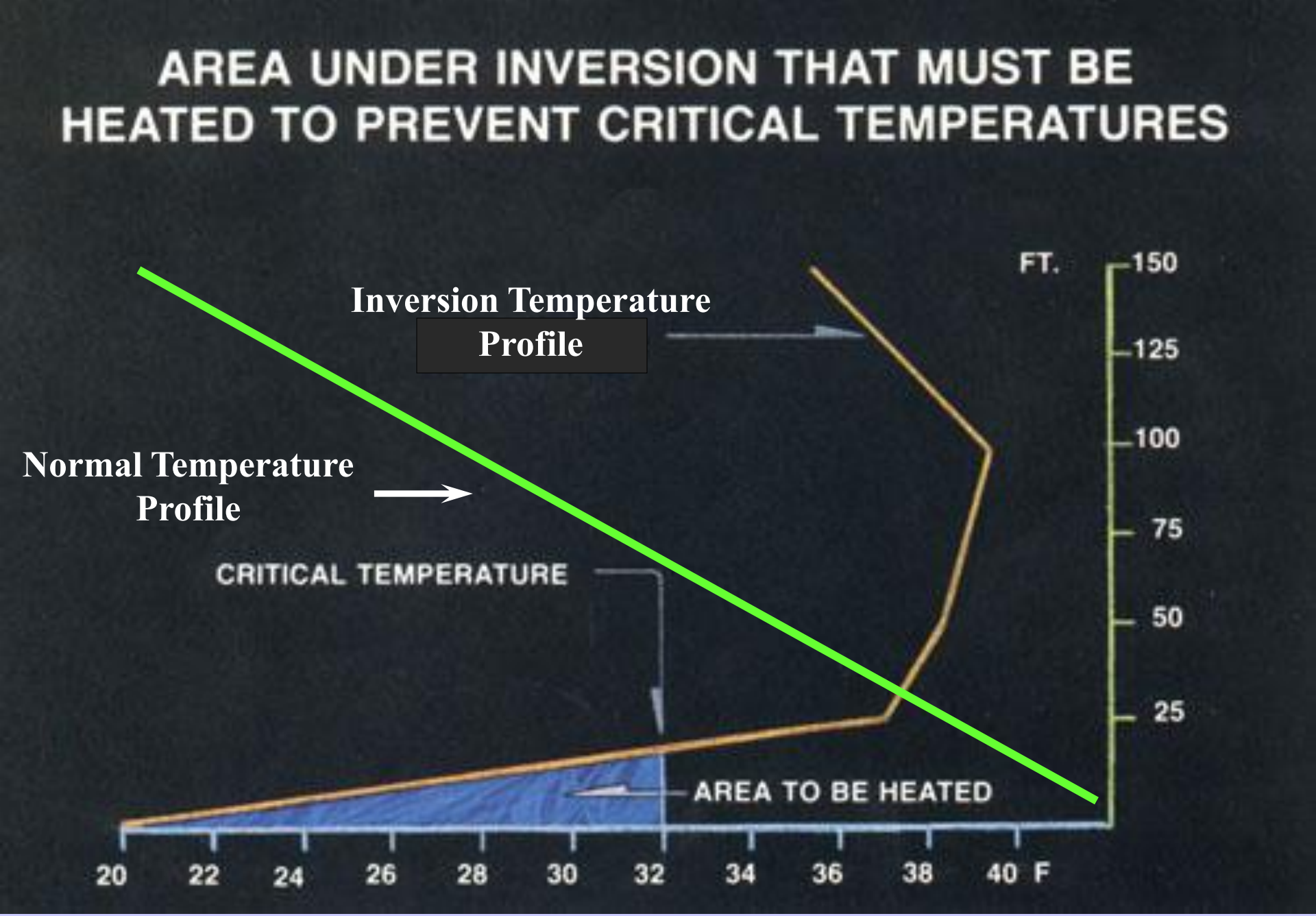

AREA UNDER INVERSION THAT MUST BE HEATED TO PREVENT CRITICAL TEMPERATURES
Inversion Temperature Profile
Normal Temperature Profile
CRITICAL TEMPERATURE
AREA TO BE HEATED
FT.
150
125
100
75
50
25
20
22
24
26
28
30
32
34
36
38
40 F

Figure 09

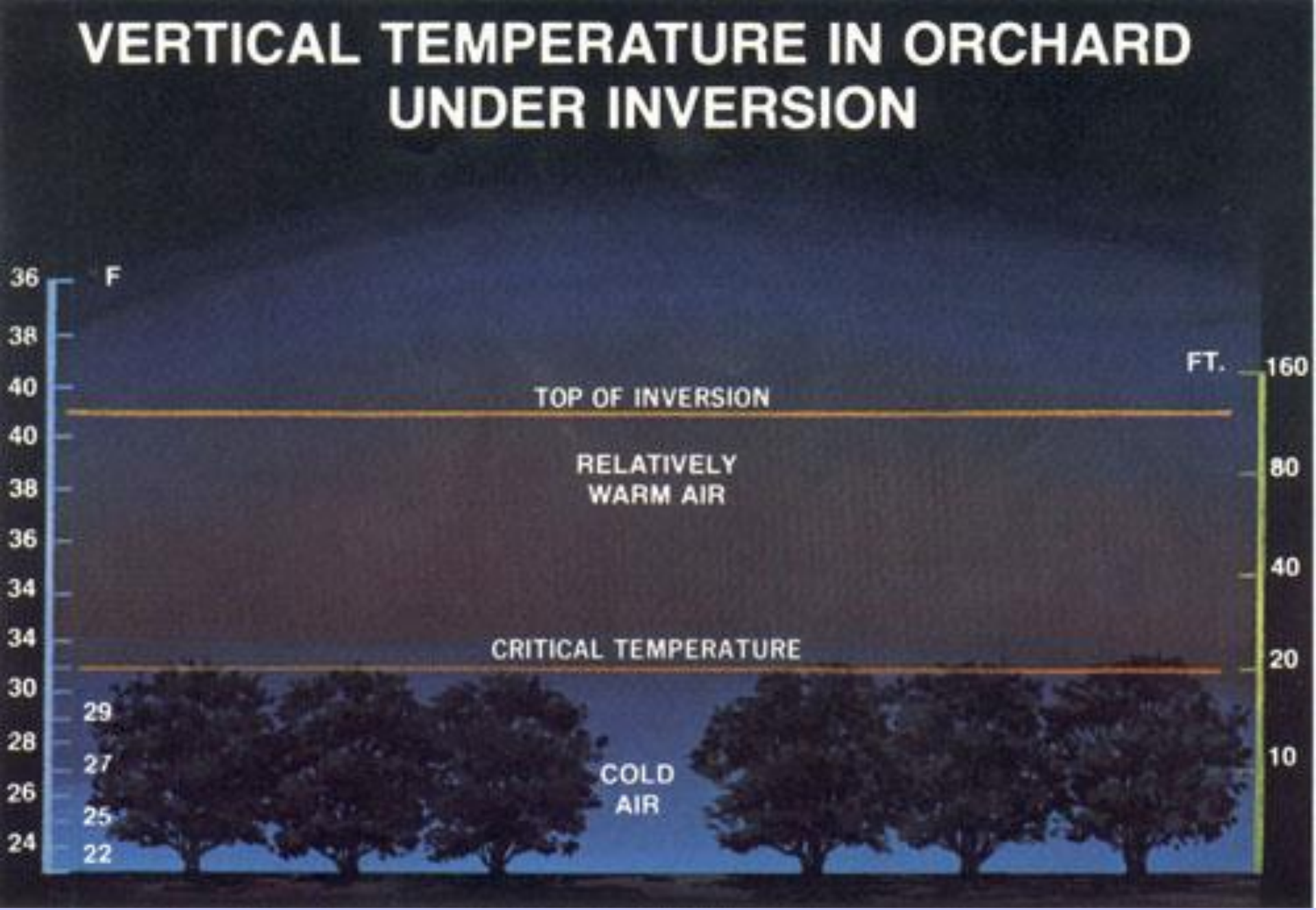

VERTICAL TEMPERATURE IN ORCHARD
UNDER INVERSION
36
F
38
40
40
38
36
34
34
30
29
28
27
26
25
24
22
FT.
160
80
40
20
10
TOP OF INVERSION
RELATIVELY
WARM AIR
CRITICAL TEMPERATURE
COLD
AIR

Figure 12

Inversion

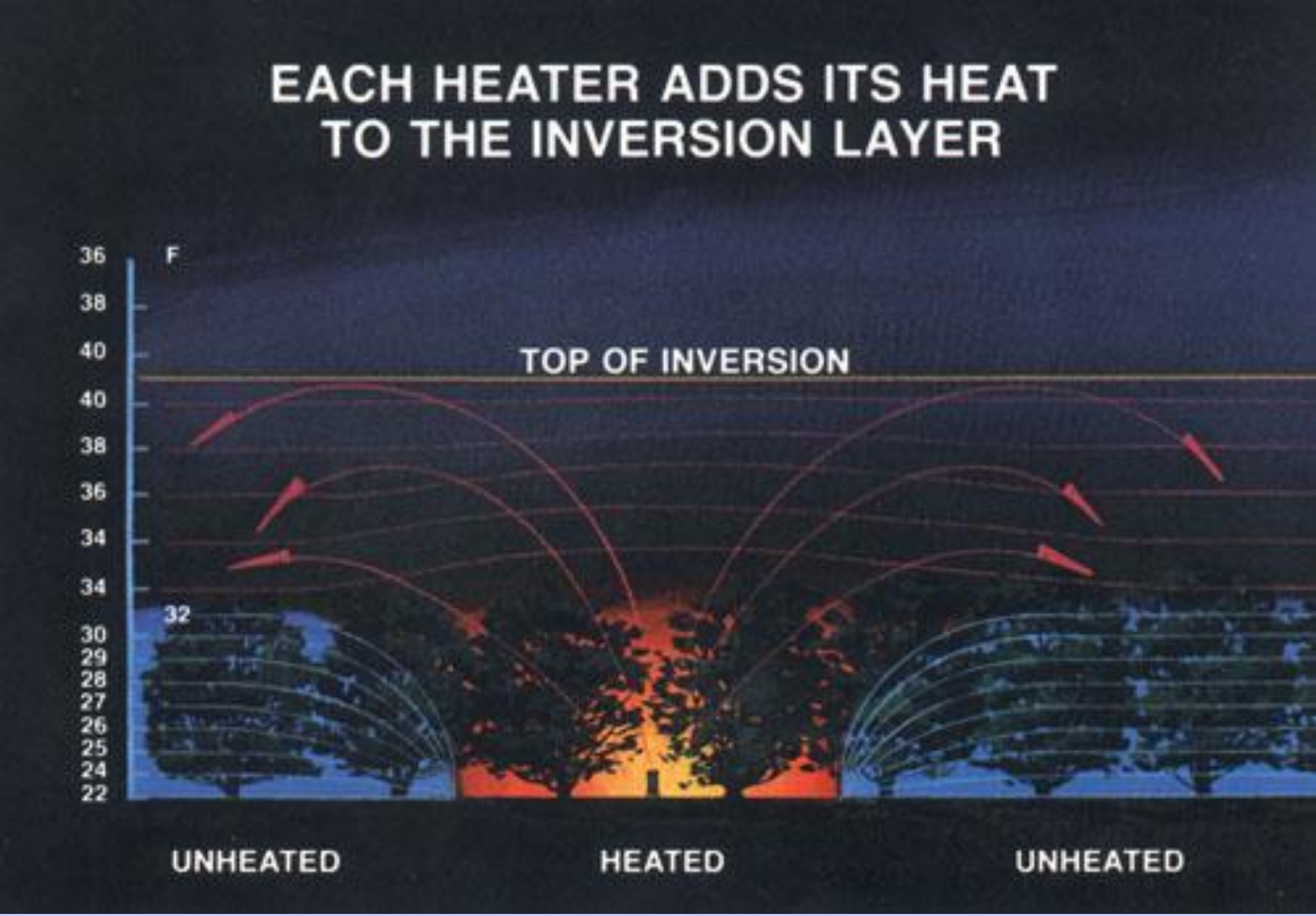


Figure 15

Top Down Process

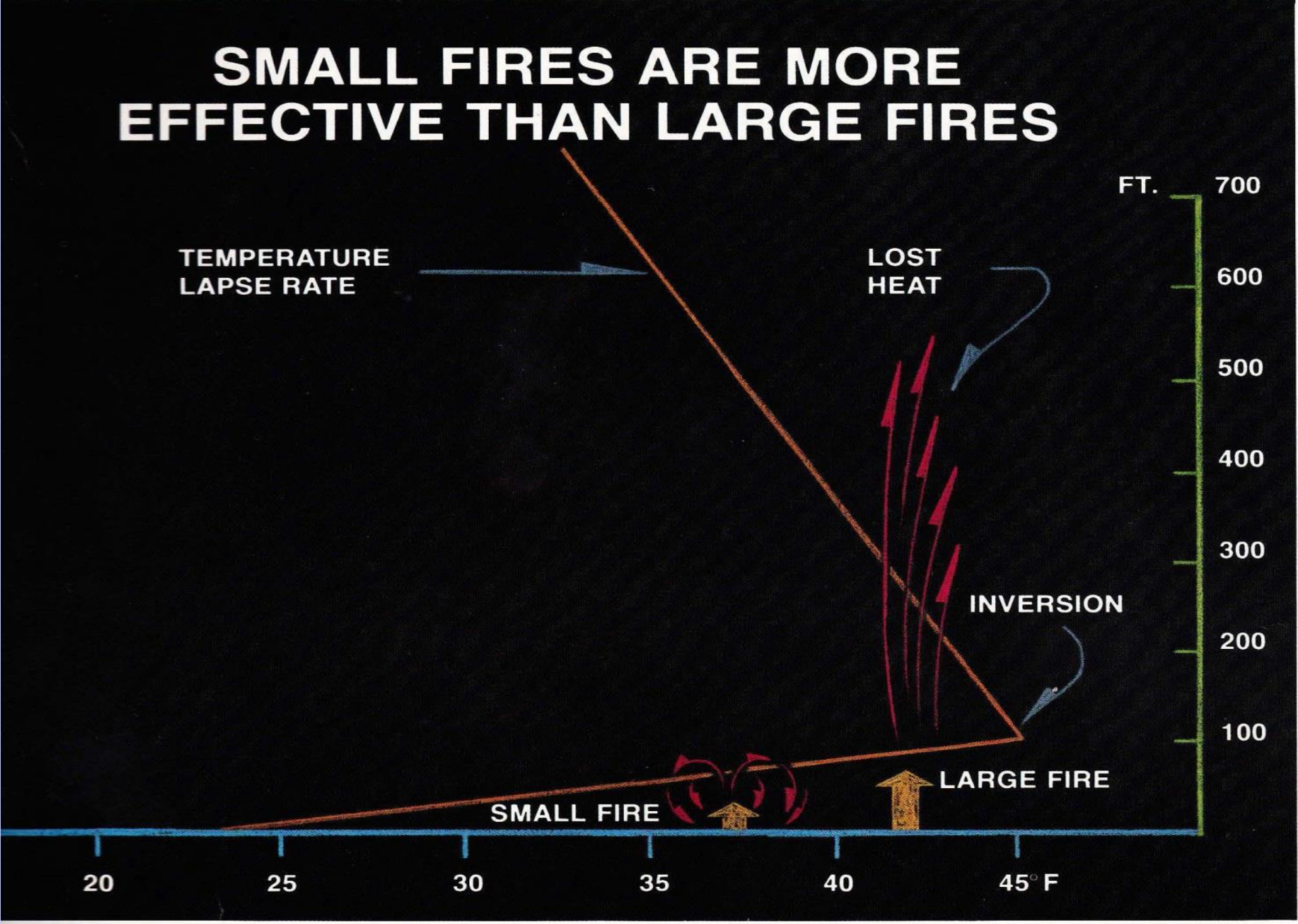

SMALL FIRES ARE MORE EFFECTIVE THAN LARGE FIRES
FT.
700
600
500
400
300
200
100
TEMPERATURE LAPSE RATE
LOST HEAT
INVERSION
LARGE FIRE
SMALL FIRE
20
25
30
35
40
45° F

Figure 10

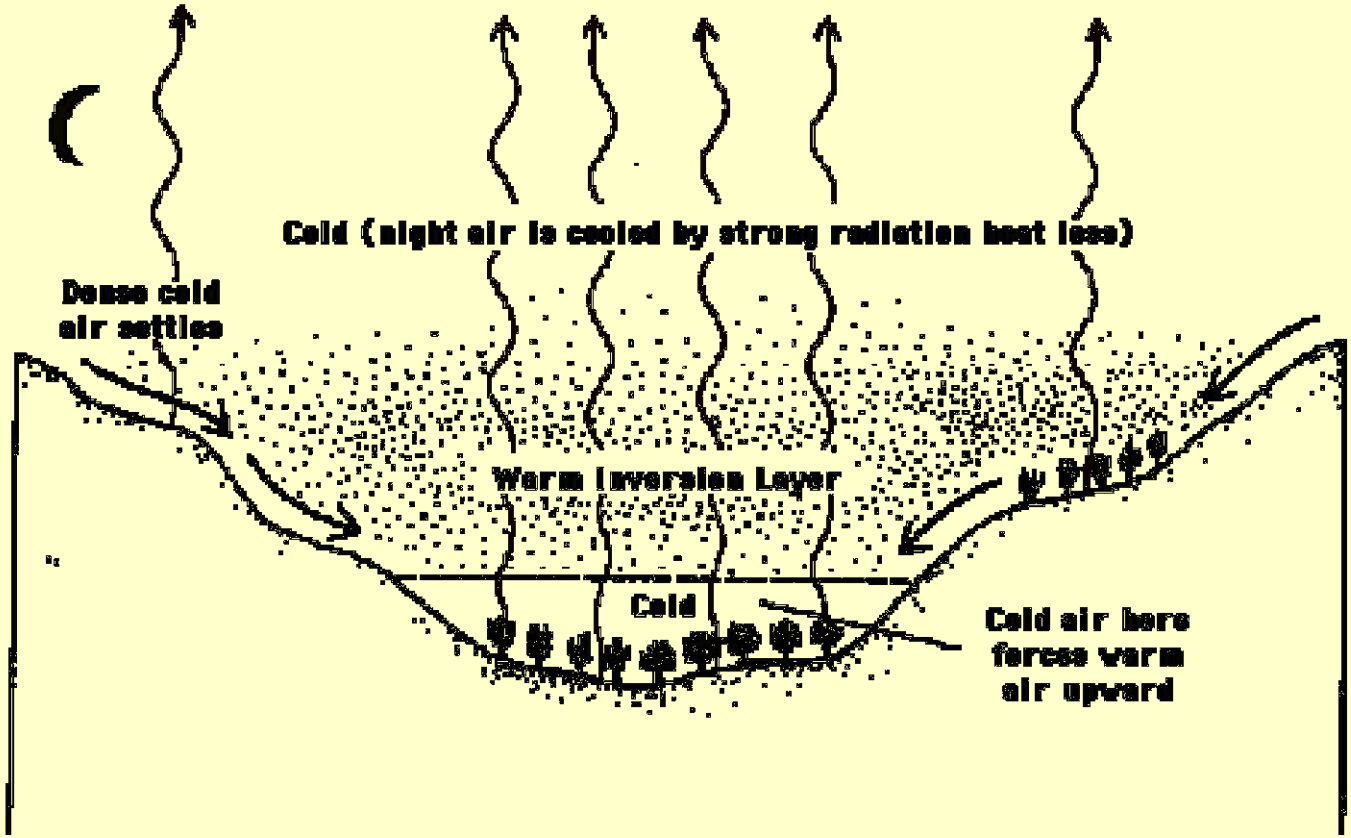
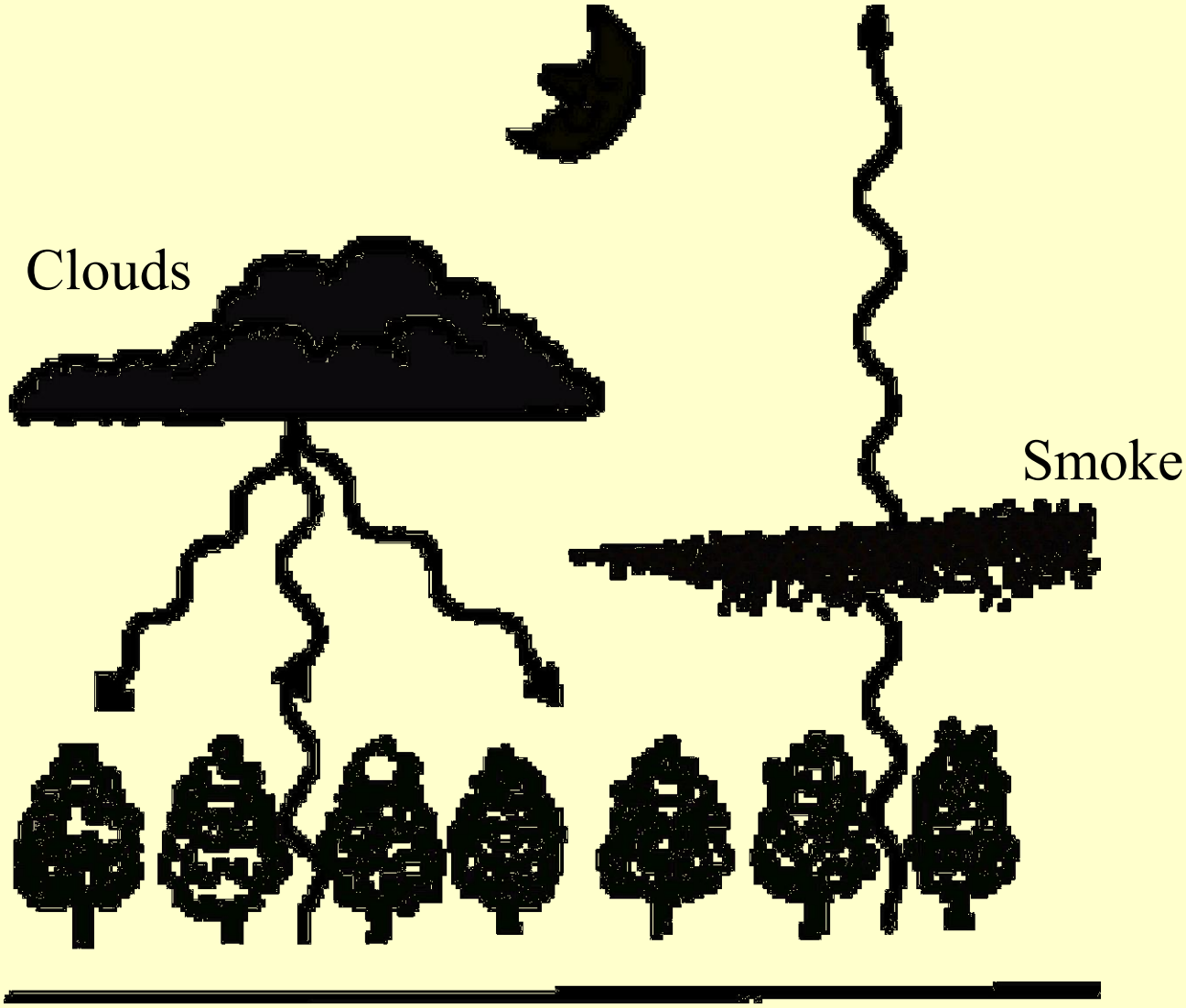


Figure 16-19 pg. 409, Westwood. 1993.


Clouds
Smoke

Dewpoint: temperature at which moisture begins to condense from an air mass.

The more water vapor in the air the higher the dewpoint

If the dewpoint is above freezing the temperature drop will be slower.

Low dewpoints indicate dry air and more difficulty in heating the orchard.

Frost Damage Symptoms

Monitoring Frost

Passive Methods of Frost Protection

- **Site Selection**
- Soils
  - Soil color – dark
  - Soil water content
  - Soil type – gravelly
- Ground cover management

Effects of Ground Cover on Temperatures

• Bare, firm, moist ground	warmest
• Shredded cover crop, moist ground	½°F colder
• Low-growing cover crop	1°-3°F colder
• Dry, firm ground.	2°F colder
• Freshly disked, fluffy ground	2°F colder
• High cover crop	2°-4°Fcolder
• Where cover crop restricts air drainage	6°-8°F colder

Active Methods of Frost Control

- Heaters
- Wind Machines
- Helicopters
- Over-tree Irrigation
- Under-tree Irrigation
- Ice-nucleating bacteria
- Application of “anti-freeze” materials
- Frost Avoidance

“Frost Dragon”®
Mobile Propane Heater

Wind Machines

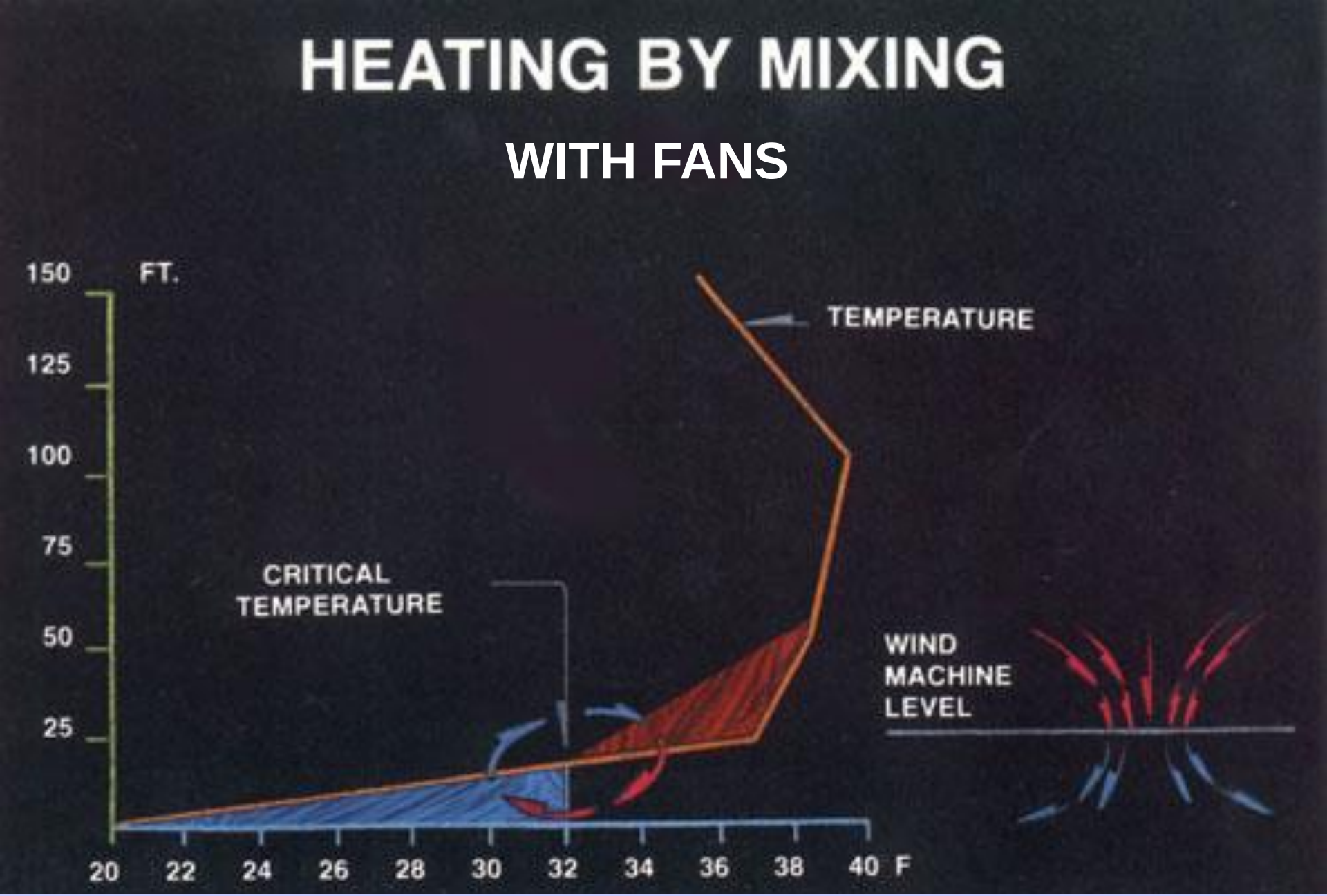

HEATING BY MIXING
WITH FANS
150
FT.
125
100
75
50
25
TEMPERATURE
CRITICAL
TEMPERATURE
WIND
MACHINE
LEVEL
20
22
24
26
28
30
32
34
36
38
40 F

Figure 16

Image from Phil Brown Welding Corp.

Sprinkling During Frost

- Amt. of water depends upon temperature & environmental conditions (0.1 to 0.15 in/hr)
- Intermittent sprinkling 1 on 3 off
- Can protect down to 24F
- Turn off when ice is melting and temperatures are rising
- Normally a permanent set up

Frost Avoidance

- Frost Avoidance through Bloom Delay
  - effective but…
    - reduced fruit set
    - copious amounts of water

Other Methods Mentioned

- Helicopters
- Under – tree irrigation
- Ice-nucleating bacteria destruction*
- Application of “anti-freeze” materials*
  - ethephon, soybean oil, ABA, nutrients

*To date, no scientifically validated materials have proven successful in field trials

Credits

- Colored drawings adapted from Valli, V. J. 1971. Basic principles of freeze occurrence and the prevention of freeze damage to crops. USDA.
- Polar vortex image from Accuweather
- Other photos from R. M. Crassweller