

UNDERSTANDING FROST AND FREEZE EVENTS

Michael Fargione
CCE Eastern NY Commercial Horticulture Program
Empire State Producers Expo
January 22, 2013



2012 will likely be remembered for the significant cold injury damage that occurred to fruit during the spring season.

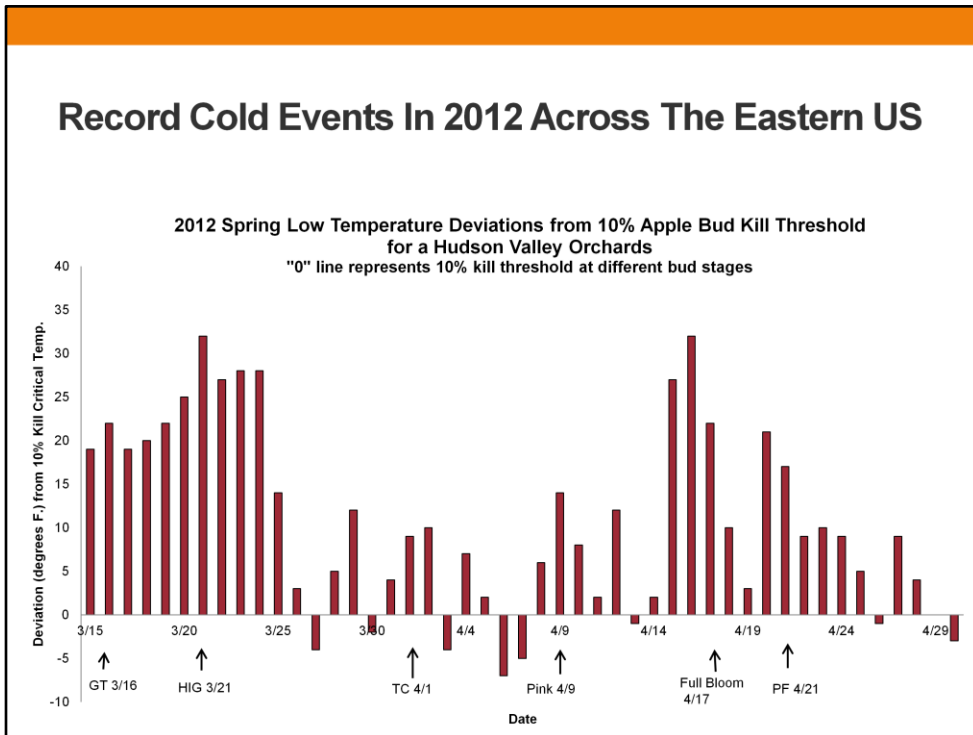
Our scheduled first speaker this afternoon was unable to attend today. Unable to secure a last minute pinch hitter, I found myself late last week preparing to give this first talk.

I am definitely not a meteorologist, but will attempt to “set the table” for our other speakers. A copy of talk is on table in back.

Minimizing Frost & Freeze Damage

- Understanding cold event terminology and processes.
- Preparing for the event by evaluating forecast products at multiple intervals.
- Selecting a plan of action based on type of event likely to occur.
- Continual monitoring during the event for changes from predicted conditions, and reacting accordingly.

To be successful at minimizing cold damage in orchards such as frosts and freezes, it is helpful to be aware of the following issues:



Here is an illustration of what happened during the spring of 2012, using one site in ENY as an example.

The horizontal axis shows time from March 15 through April 30; It also shows tree phenology.

As you know, at each bud stage there are published critical temperatures where cold damage can be expected. Typically these critical temperatures are represented as the temperature when 10% kill or 90% kill of fruit buds is expected. These critical temperatures vary by phenological bud stage.

The zero line in this graph represents the 10% kill temperature for a given bud stage. The height of each red bar shows that day's minimum temperature in relation to the published critical temperature for that bud stage (or how many degrees below the critical temperature was reached if the red bar is below the zero line).

This orchard experienced at least 8 days during 2012 when some level of cold injury would have been expected to occur.



The impacts of last year's cold events are far too familiar to all of us and not what we are speaking about this morning. What I would like to consider now is why was the potential for cold injury so great last season?

2012 Was One of the Earliest Seasons On Record

'McIntosh' Phenology
Hudson Valley Lab, Highland, NY

Green Tip

30-year Average = April 4

2012 = March 16

Full Bloom

50-year Average = May 3

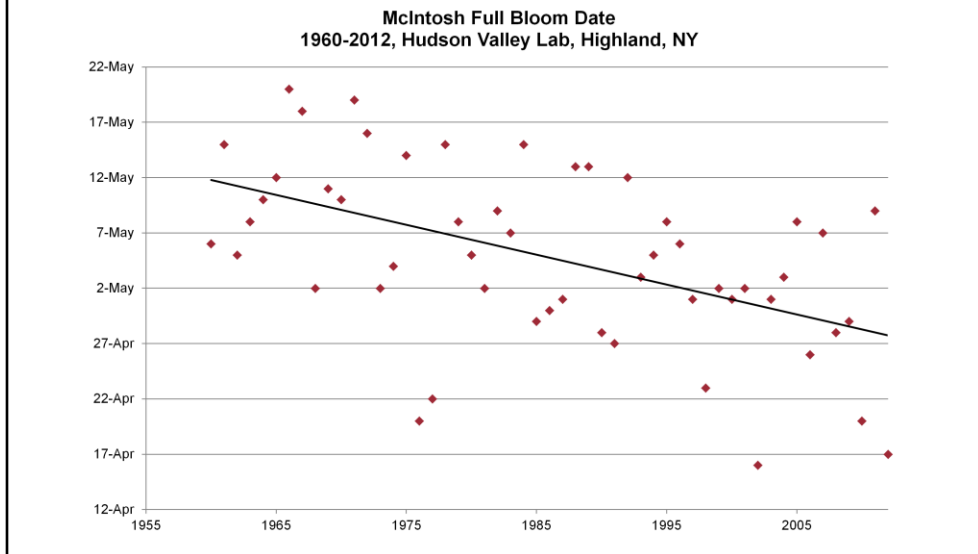
2012 = April 17

Lets look at how tree development in 2012 compared to an average season. Again, I am presenting some Eastern NY data; this time relating to 'McIntosh' apple tree bud stages.

(review slide)

Clearly, last year was a phenomenally-early season, but was it a fluke? Can we expect similar conditions in the future?

Apple Tree Phenology Shifting To Earlier Timing



In fact, the trend has been toward an increasingly earlier start to our growing seasons. This graph shows full bloom data for 'McIntosh', again from the Eastern NY, from 1960-2012.

(review slide)

The black line is the trend line of full bloom dates, and it clearly indicates a trend in increasingly early bloom over this period. A similar phenomenon would be seen if you plotted data collected in other regions in the state.

So, the trend is that our growing seasons have started to occur earlier. Why might this be so?

NYS Has Become Warmer, Especially During The Winter!

Observed climate trends in NYS 1970-2008

(source: 2011 Response to Climate Change in New York State Report 11-18 ClimAID)

	Annual (°F/decade)	Spring (°F/decade)	Summer (°F/decade)	Fall (°F/decade)	Winter (°F/decade)
Albany	0.64**	0.23	0.69**	0.47	1.23**
Elmira	0.61**	0.31	0.71**	0.44	1.04*
Indian Lake	0.70**	0.36	0.38	0.73**	1.39**
NYC	0.60**	0.43	0.31	0.47*	1.23**
Port Jervis	0.43**	0.05	0.51**	0.45*	0.78
Rochester	0.49**	0.27	0.23	0.36	1.18**
Watertown	0.57**	0.21	0.39	0.60*	1.15*

Temperature in °F per decade

* Significant at the 95% level. ** Significant at the 99% level.

Data from across NY suggests that our climate has warmed measurably, even since as late as the 1970's.

This table shows how average temperatures per decade have changed between 1970-2008.

(review slide)

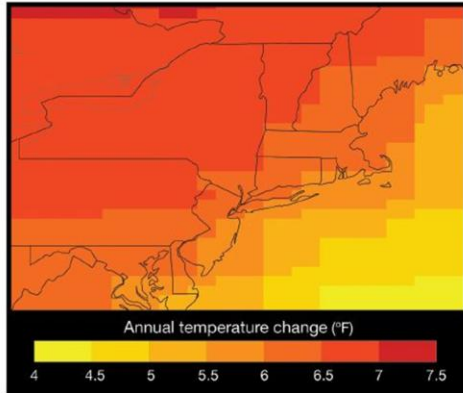
Note that the greatest increases in warming have been during the winter months.

Warming during winter seasons may be particularly significant as it could explain the observed trend toward an earlier onset of the growing season.

Will this trend continue?

Average NYS Temperatures Are Predicted To Increase Another 4-9°F By The 2080's!

Projected change in annual temperature for the 2080's
(source: 2011 Response to Climate Change in New York State Report 11-18 ClimAID)



Source: Columbia University Center for Climate Systems Research. Data are from WCRP and PCMDI

Warming temperatures will continue.

Continued trend of earlier bud break and bloom timing.

Frosts are likely to remain a threat and perhaps increase in the future.

Numerous models have been published that predict warming temperatures will continue. Conservative models suggest the warming trend may increase 4-9 degrees F⁰ before the end of this century.

(review slide)

The risk of more frequent cold events seems likely. Management of cold events may become an increasingly important consideration for the fruit industry.

Understanding Cold Events

Now lets look at the different types of cold events that are of concern in the orchard during spring.

Frosts and freezes are not the same, and different strategies are need to protect orchards from cold injury caused by them.

Terminology

First we should review some terminology

Heat Transfer - Conduction

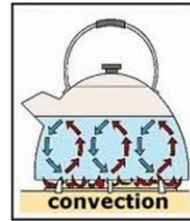
- Conduction – heated molecules move faster and transfer energy by their bumping into each other. Conduction establishes a heat gradient (example: movement of heat through metal or soil).



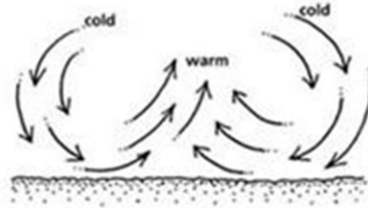
Cold weather events are all about the changes in temperature within the orchard resulting from the transfer of heat. There are various methods by which heat transfer can occur. The first of these is called conduction.

Heat Transfer - Convection

- Convection – transfer by movement of heated liquid or gas (such as air) through mass movement of the material (example warm water is less dense and rises in a tea kettle. Cooler water replaces it causing a circulating movement).



Fluid movement of heated air

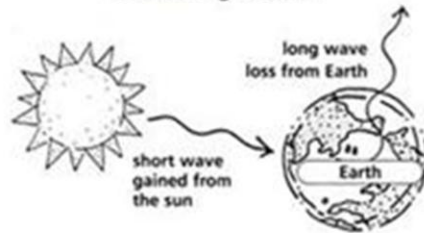


Heat Transfer - Radiation

- Radiation – Heat transfer from one object to another without them being physically connected via electromagnetic waves (example – objects placed in front of a fire or in the sun become warmer than the air around them).



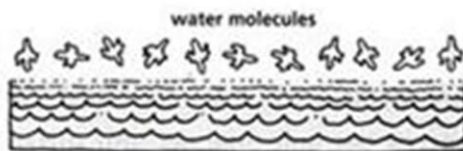
Energy passing from one object to another without a connecting medium



Heat Transfer – Latent Heat

LATENT HEAT

Chemical energy due to
water phase changes
(evaporation, condensation, etc.)
and water vapour transfer



- Heat of Fusion: As liquid water freezes, 80 kcal/liter are released.
- Heat of Condensation: As water goes from a gas to a liquid, it releases 539 kcal/liter.
- (reverse of above is also true - Heat of vaporization: As water goes from a liquid to a gas, it removes 539 kcal/liter.)

Heat of fusion is important in frost protection with overhead sprinklers. It is the released heat as water freezes that provides the protection. The ice does not act as an insulator.

Heat of condensation releases about 7X the heat as heat of fusion and is important in frost protection in at least 2 ways:

First it provides significant natural heating when temperatures reach the dew point and water vapor is converted to liquid water as dew or fog.

Second, it can be manipulated with sprinklers, particularly under-tree sprinklers that increase the water vapor in the orchard and provide more vapor to be converted to liquid water, thus releasing its heat of condensation. Dr. Terence Robinson has indicated this is the major form of frost protection used in the part of Mexico where he grew up.

The reverse also happens and is the reason why stopping irrigation during frost protection results in more damage to plants.

Dew Point



- Temperature at which water vapor in air becomes saturated and condenses into fog, dew or frost.
- Value indicates the total amount of water vapor in the air, and is constant regardless of temperature (unlike relative humidity which is temperature dependent).
- Relatively high dew points (upper 20's or higher) indicate moist lower atmosphere, slower drop in temperature will occur, and hoar frost is the form likely to occur.
- Relatively low dew points (mid 20's or lower) indicate drier lower atmosphere, more rapid temperature drop, and black frost is the form most likely to occur.
- Dew point below 32°F is called a "frost point".

Understanding dew points may help you to interpret and predict how cold events will progress and what actions are best taken to prevent plant damage.

What is Frost?

- Frost consists of ice crystals that grow out from a solid surface.
- It forms from water vapor when a solid surface (such as a bud, flower or leaf) is chilled below the dew point of the surrounding air and becomes colder than the freezing point.
- Frost damages plants when ice crystals form within the cells.
- It can occur when air temperatures are still above freezing. Plant tissue can be cooler than the air due to radiational cooling and certain bacteria (including *Pseudomonas syringae*) can trigger frost formation by raising nucleation temperature.
- Yet, damage does not always occur when plant tissue drops $\leq 32^{\circ}\text{F}$ because:
 - The contents of the cell lower the freezing point (like anti-freeze).
 - The formation of ice requires a site of ice crystal nucleation.

We have mentioned frost a number of times, but just what is it?

Hoar Frost

White frost that results when atmospheric moisture freezes in small crystals on solid surfaces.



There are 2 kinds of frost. The first is called hoar frost and is visible.

Black Frost

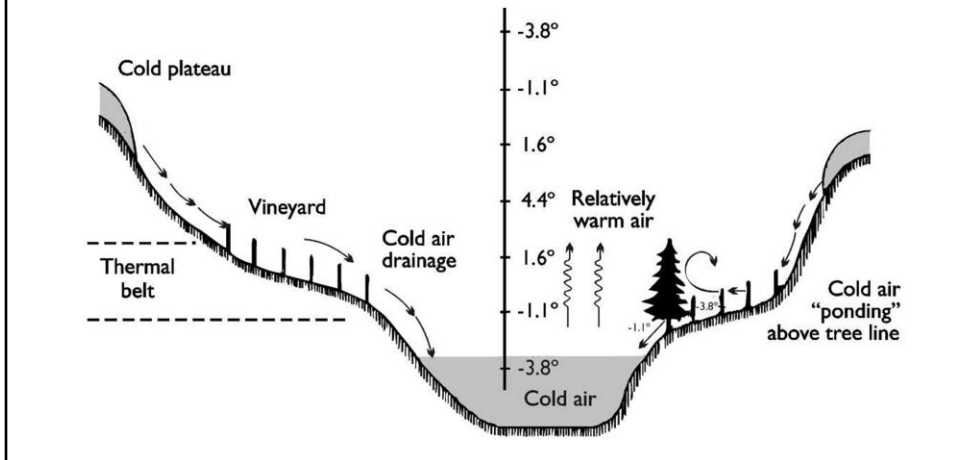
Occurs when air temperatures drop below freezing but the air does not contain enough water for visible surface ice crystals to form. No visible frost will appear to indicate protective measures are needed.



The second is called black frost. A lack of sufficient water vapor in the air prevents us from seeing black frost, but freezing and subsequent damage within plant cells may still be taking place.

Temperature Inversion

A shallow layer of air near the earth's surface where the temperature increases with height.



Another key concept to be aware of is the temperature inversion.
(review slide)

Heat trapped by the surface radiates out at night and the air nearest to the ground becomes colder than the air above it.

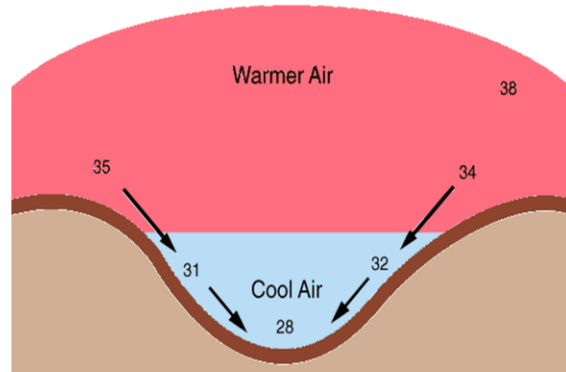
In addition, cold air from surrounding elevations flows down hill (due to heavier density) and collect in low spots.

Inversions become key sources of heat for active frost protection methods.

Temperature Inversion

Thickness of inversion depends upon weather conditions and topography.

- Typically 100 m in depth.
- Can range from 10-1000m
- Strong inversion can be 7-10°F or more warmer than surface.



(length of the inversion are calculated by comparing difference between the temperature at elevations of 50' vs. 5'. For example, 4 degree F difference at 50' compared with 5' may mean the inversion has the potential to supply 1-2 degrees F additional warming of the air near the plants if the air can be circulated.

Characteristics of a Frost Versus a Freeze

Radiational Frost

- Calm winds (< 5 mph)
- Clear skies
- Inversion 30-200' deep (may) develop
- Cold air drainage occurs
- Two types: Hoar (white) black
- Successful frost protection likely

Advection Freeze

- Winds above 5 mph
- Clouds may exist
- Cold air mass 500-5000' deep
- Associated with the passage of large frontal systems of very cold air over an entire region
- Frost protection limited.

National Weather Service Definitions

Warning	Wind Speed	Air Temp (5')
FROST	< 10 mph	$\geq 32^{\circ}\text{F}^*$
FROST/FREEZE	< 10 mph	$< 32^{\circ}\text{F}$
FREEZE	≥ 10 mph	$< 32^{\circ}\text{F}$

* Objects like plant can be colder than the air due to radiational cooling

The National Weather Service has specific definitions of frosts and freezes that are dependent on wind speed and air temperatures.

(Review slide)

Understanding their definitions will allow growers to better understand the specific meaning of weather forecasts and what remedies might be effective.

Cold Event Preparedness (Don't be caught off-guard!)

Critical Weather Forecast Products

- Minimum temperature (forecast @ 5')
- Wind speed (weakest link – forecast for 10 m height)
- % Cloud cover
- Dew point temperature
- Start and duration of time below freezing

Other Useful Products

- Inversion strength and height
- Hourly wet bulb temperature (for orchard sprinklers)

After Poling, E. B. 2008. HortScience Vol. 43(6) 1652-1662

Examining and understanding weather forecasts is a key step necessary to take effective action to limit cold injury.

Forecast Resources

National Weather Service Hourly Forecast

http://www.nrcc.cornell.edu/nws_cwa.html

National Weather Service Offices in the Northeast

Click on a forecast area to visit that NWS Office's web page



There are a multitude of weather forecast services available, both public and private. You probably want to look at several.

National Weather Service does provide hourly forecasts:

- Hourly forecasts issued at for 1 km grids
- Major updates twice daily
- Short term updates 2+ times daily
- Warning are issued at County Scale

Private Company Forecasts:

- Fee Based
- Frost/Freeze Alerts
- Site Specific and Customizable

National Weather Service Hourly Forecast

http://www.nrcc.cornell.edu/nws_cwa.html

Albany, NY

News

Organization

Search for:

NWS



- Read watches, warnings & advisories
- Zoom Out**
- High Wind Warning
 - Gale Warning
 - Lake Effect Snow Advisory
 - Wind Advisory
 - Special Weather Statement
 - Hazardous Weather Outlook

Hourly Weather Graph

- Select City/Location
- Albany NY
 - Bennington NH
 - Binghamton NY
 - Concord NH
 - Glens Falls NY
 - Hartford NY
 - Hunter NY

Submit

Latitude/Longitude Entry
decimal degrees (i.e. 42.134) or
deg min sec (i.e. 42 23 34)

Latitude:

Longitude:

Submit

NWS's National Weather Service

Disclaimer

Privacy Policy

Finding the hourly forecast for your area.

[hide menu] | Font Size: **A A A**

Weather Elements		Weather/Precipitation	
<input checked="" type="checkbox"/> Temperature (°F)	<input checked="" type="checkbox"/> Surface Wind mph	<input checked="" type="checkbox"/> Thunder	
<input checked="" type="checkbox"/> Dewpoint (°F)	<input checked="" type="checkbox"/> Sky Coverage	<input checked="" type="checkbox"/> Rain	
<input checked="" type="checkbox"/> Wind Chill (°F)	<input checked="" type="checkbox"/> Precipitation Potential	<input checked="" type="checkbox"/> Snow	
	<input checked="" type="checkbox"/> Relative Humidity	<input checked="" type="checkbox"/> Freezing Rain	
		<input checked="" type="checkbox"/> Sleet	

48-Hour Period Starting: 11am Sun, Jan 20 2013

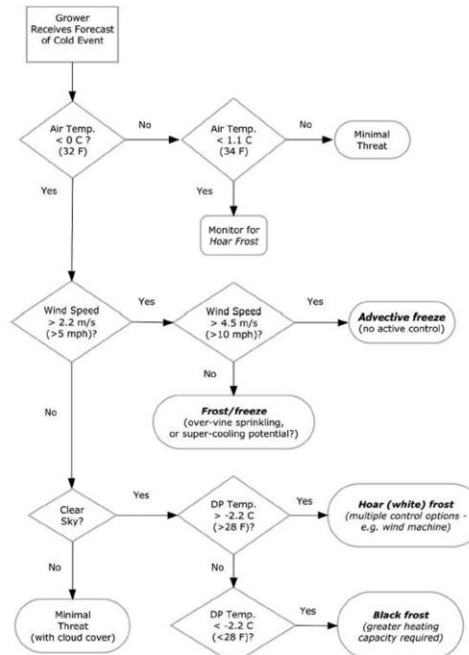
Date	01/20											01/21												
Hour (EST)	11	12	13	14	15	16	17	18	19	20	21	22	23	00	01	02	03	04	05	06	07	08	09	10
Temperature (°F)	39	39	39	37	35	32	31	29	28	26	25	23	21	20	19	18	18	17	16	16	15	16	18	21
Dewpoint (°F)	22	20	18	16	14	13	12	11	11	10	10	9	9	8	8	8	8	8	7	7	7	7	8	9
Wind Chill (°F)	29	29	29	26	24	21	20	18	17	15	14	12	10	9	9	9	9	9	9	9	9	9	11	13
Wind (mph)	21	22	22	21	20	17	16	14	13	11	11	11	10	9	8	7	7	6	5	5	3	5	5	6
Wind Dir	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	SW	SW	SW	SW
Gust	37	40	48	37	34	30	29	24		21	21	21												
Sky Cover (%)	49	50	50	50	50	50	50	50	50	50	50	50	50	51	51	52	55	57	60	62	64	66	72	77
Pcpn. Potential (%)	24	25	22	19	15	17	18	20	17	17	17	17	17	17	17	17	17	17	17	17	22	26	31	36
Rel. Humidity (%)	50	46	42	42	41	45	45	46	48	50	52	54	59	59	61	64	64	67	67	67	70	67	64	59
Thunder	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rain	SChc	Chc	SChc	SChc	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Snow	SChc	Chc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	SChc	Chc	Chc	Chc
Freezing Rain	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sleet	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Finding the hourly forecast for your area (continued).

Making Informed Judgments:

Cold Event Monitoring and Decision Chart

After Poling, E. B. 2008.
HortScience Vol. 43(6) 1652-1662



How do you effectively interpret the forecast data you have assembled?

Growers who have years of experience develop a keen sense of how to put it all together, predict the probable conditions that will occur, and choose a successful response.

Inexperienced growers might consult with an experienced grower, CCE specialist or private consultant.

Here is a decision making chart on how to interpret and make action plans. This one is for a vineyard but will likely work for orchards as well.

A copy is in the handout on the back table.

Event Diagnosis

Monitor 72-h, 48-h, and 24-h forecasts

Step 1. Observe minimum temperature forecasts:

- If predicted temperature has the potential to go to 34°F (1.1°C) or less, be alert for the potential for hoar frost.
- Hoar frost can form at air temperatures above 32°F if calm winds, clear skies and dew point temperature of 34-36°F (1.1-2.2°C).

If subfreezing temperatures are forecast, then go to Step 2.

After Poling, E. B. 2008. HortScience Vol. 43(6) 1652-1662

Let's simplify the decision chart shown previously.
(Review slide)

Event Diagnosis

Examine 72-h, 48-h, and 24-h forecasts

Step 2. Evaluate wind speed forecasts:

- Forecasts of winds > 10 mph with subfreezing temperatures indicates a freeze is likely and no active control measures are recommended.
- Forecast winds of 5-10 mph with subfreezing temperatures indicates a frost/freeze is likely and limited control options exist.
- If forecasts predict winds < 5 mph with temperatures on the ground below 32°F (0°C), then you are dealing with some form of radiational cooling event. Go to step 3.

After Poling, E. B. 2008. HortScience Vol. 43(6) 1652-1662

Decision chart (continued).

Event Diagnosis

Examine 72-h, 48-h, and 24-h forecasts

Step 3. Evaluate atmospheric humidity with dew point temperature:

- A relatively high dew point ($>28^{\circ}\text{F}$ or -2.2°C) indicates relatively moist air and the potential for hoar frost.
- A relatively low dew point ($\leq 28^{\circ}\text{F}$ or -2.2°C) indicates drier air and the potential for a killing black frost.
- Plan your management strategy.

After Poling, E. B. 2008. HortScience Vol. 43(6) 1652-1662

Decision chart (continued).

Management Options Given Different Cold Events

Method	Radiational hoar frost; temp -2.2 to 2.2 °C	Radiational black frost and/or weak inversion; temp below -2.2 °C	Frost/freeze and temp below -2.2 °C (winds of 2.2 m·s ⁻¹ to 4.5 m·s ⁻¹)
Good site selection (passive)	Highly effective	Effective	Limited effectiveness
Wind machine	Highly effective	Limited effectiveness	Ineffective, potentially damaging
Wind machine plus heaters	Not applicable	Effective	Limited effectiveness
Wind machine plus helicopter	Not applicable	Highly effective	Ineffective
Overvine sprinkling	Highly effective	Highly effective	Effective
Helicopter	Highly effective	Effective	Ineffective, potentially damaging
Heaters	Highly effective	Effective	Effective

Choosing the wrong mediation techniques can result in increased damage compared to doing nothing at all!

As you can see, within radiational cold events, more options exist to control hoar frosts than black frosts.

You have a lot more options for effective damage prevention when a radiational cold event occurs than when a freeze takes place.

In Summary

- Understanding cold event terminology and processes.
- Preparing for the event by evaluating forecast products at multiple intervals.
- Selecting a plan of action based on type of event likely to occur.
- Continual monitoring for changes from predicted conditions and reacting accordingly.

References

DeGaetano, A. 2011. Weather 101 – Understanding Frost. Presentation at Empire State Fruit & Vegetable Expo., Syracuse, NY.

Perry, K.B. 2001. Frost/freezing protection for horticultural crops. Hort. Info. Leaflet 705, North Carolina Coop. Ext. Serv., NC State University, Raleigh.

Poling, E. B. 2008. Spring cold injury to wine grapes and protection strategies and methods. HortScience Vol. 43(6) 1652-1662.

Risks in Response to Climate Change in New York State. Report 11-18 ClimAID (chapters 1 & 7):
<http://www.nyserda.ny.gov/en/Publications/Research-and-Development-Technical-Reports/Environmental-Reports/EMEP-Publications/Response-to-Climate-Change-in-New-York.aspx>

Westwood, M.N. 1993. Temperate-Zone Pomology: Physiology and Culture. Timber Press, Oregon, pages 408-410.

References and literature cited.