



NWS Nashville Presents

Weather 101

What Makes Snow Forecasting
SO Difficult?

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Overview

- Cloud ice microphysics
 - How supercooled water plays a role in ice/snow crystal formation
 - Different types of snow crystals
- Some differences between rain-only and snow events
- Elements of a snowfall forecast
 - Snow Ratio
 - Lift
 - Moisture
 - Wet bulb temperature vs actual temperature
- What about sleet/freezing rain? Why does that occur instead of snow or rain?

Cloud Microphysics

- At what temperature does *pure* water freeze?
 - A. 32°F (0°C)
 - B. 0°F (~-18°C)
 - C. -10°F (~-23°C)
 - D. -40°F (-40°C)
 - E. -55°F (~-48°C)

Cloud Microphysics

- At what temperature does *pure* water freeze?
 - 32°F (0°C)
 - 0°F (~-18°C)
 - 10°F (~-23°C)
 - 40°F (-40°C)
 - 55°F (~-48°C)

- In the upper atmosphere

- In lab tests/research



Cloud Microphysics

- How can water stay in liquid form below 32°F?!?!
 - Water needs ice nuclei, or surface to freeze on warmer than -40°C and below 0°C. Water in the atmosphere below 0°C is known as **supercooled water**
 - Fortunately, there are plenty of particulates in the atmosphere that water uses to form ice crystals (even ice crystals themselves serve as an ice nuclei)
 - Supercooled water in the atmosphere usually doesn't get below -20°C as other ice crystals, or particulates in the air, freeze supercooled water before that temperature
 - Once supercooled water comes into contact with other ice crystals or ice nuclei (at activation temp or below) the water will freeze!



Cloud Microphysics



Homogeneous Nucleation

- **No** ice nuclei
- Usually occurs at -36°C to -40°C (Depends on droplet size)
- **Very rare** in the atmosphere due to plenty of particulates and other ice crystals present below -20°C



Heterogeneous Nucleation

- Ice nuclei **must** be present
- Usually begins at -2°C to -4°C
- **Predominant process of ice crystal formation in the atmosphere**

Cloud Microphysics

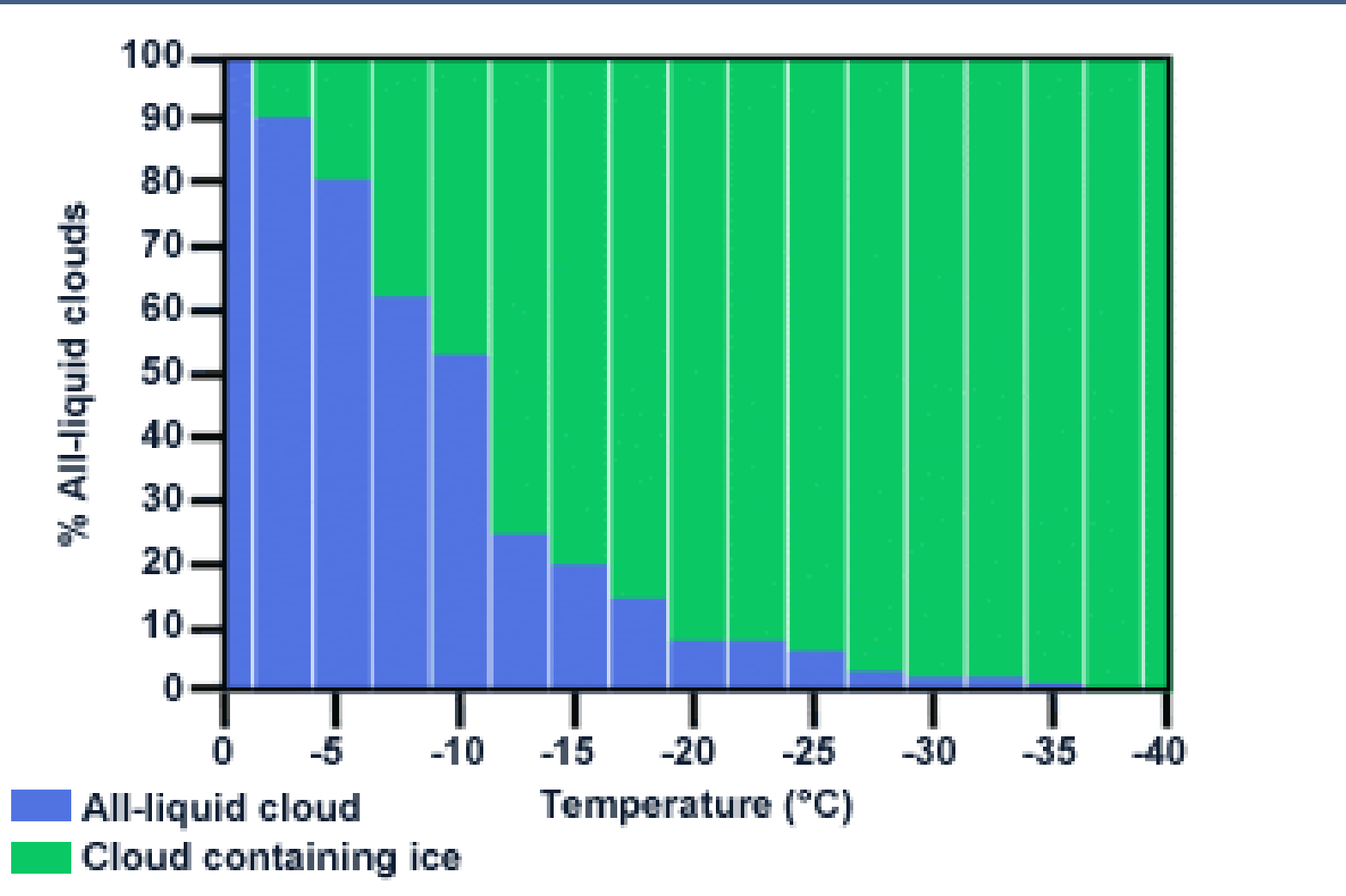
- Common ice nuclei and activation temperatures

Substance	Activation Temperature (°C)	Prevalence
leaf bacteria	-2.9	found in decaying leaf matter, possibly a prevalent source of IN
silver iodide	-4	used for artificial cloud seeding
kaolinite	-9	common clay mineral
copper sulphide	-7	pollutant
sodium chloride	-8	sea water
volcanic ash	-13	common aerosol
vermiculite	-15	common clay mineral

- The amount of ice nuclei activated in clouds increases with relative humidity (RH). Lowering cloud temps increases RH, so ice crystals are more likely to form in coldest parts of the cloud (typically towards the top)

Cloud Microphysics

All-liquid Clouds vs. Clouds Containing Ice



-4°C: Nearly no ice in clouds

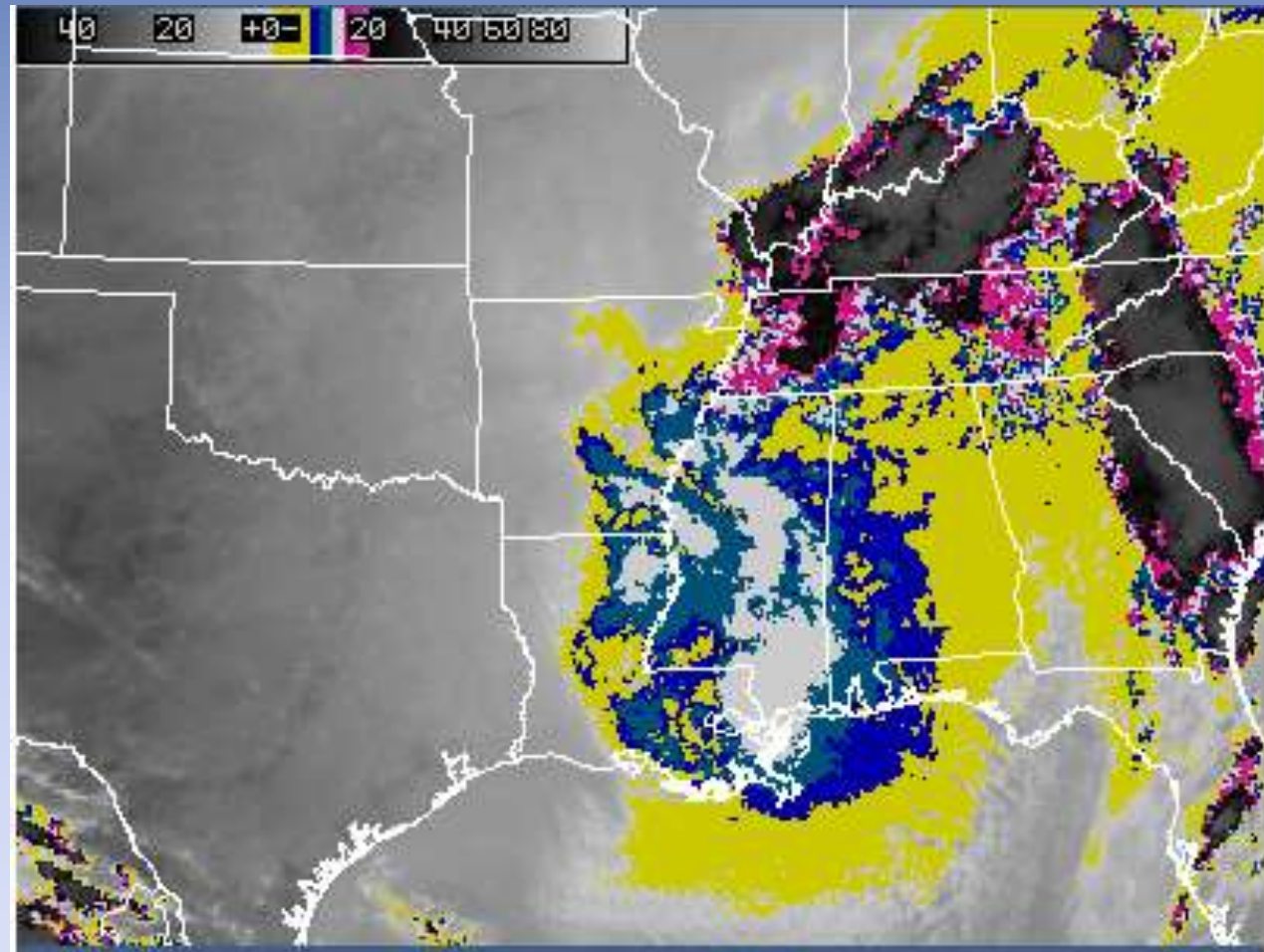
-10°C: 50-60% chance ice is in the cloud

-12°C: 70% chance

-15°C: 90% chance

-20°C: Nearly 100% chance

Cloud Microphysics

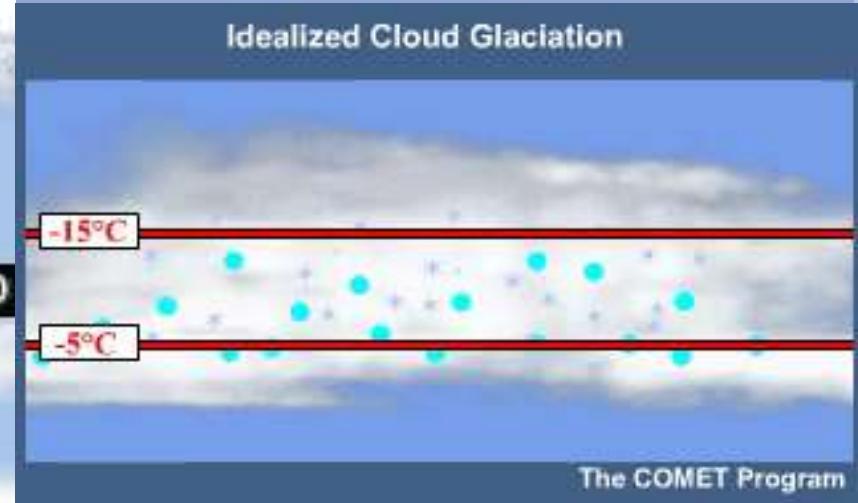
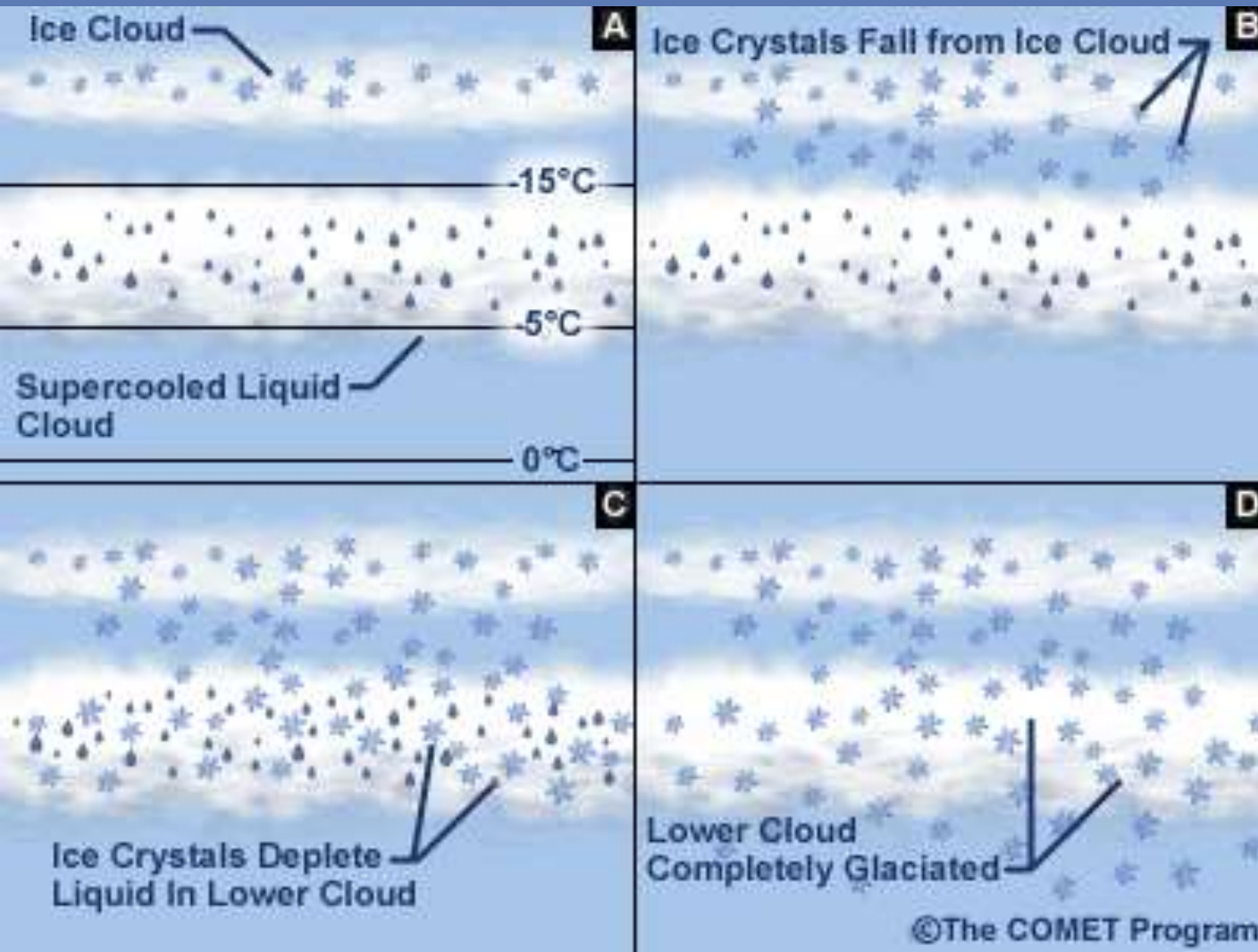


Enhancement Color	Temperature Deg (°C)	Ice or Liquid
Yellow	0 to -8	Liquid
Blue	-8 to -10	Likely Liquid
Light Blue	-10 to -12	60% Chance Ice is there
White	-12 to -15	70% Chance Ice is there
Pink	-15 to -20	90% Chance Ice is there
Black to White	-20 or less	ICE is there!

Potential presence of ice crystal initiation in clouds based on temperature

Temperature (°C)	Potential presence of ice initiation
0	no initiation
-4	no initiation
-10	60% chance of initiation and presence of ice
-12	70% chance of initiation and presence of ice
-15	90% chance of initiation and presence of ice
-20	100% chance of initiation and presence of ice

Cloud Microphysics



Cloud Microphysics

3 Ice Crystal Growth Processes:

Ice Crystal Growth by Deposition



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Deposition

- Ice crystals grow at the expense of supercooled water due to differences in saturation vapor pressure between ice (lower pressure) and liquid water (higher pressure)
- Similar pressure differences on a much larger scale are what creates wind
- **Dominant snow growth process**

Ice Crystal Growth by Accretion (Riming)

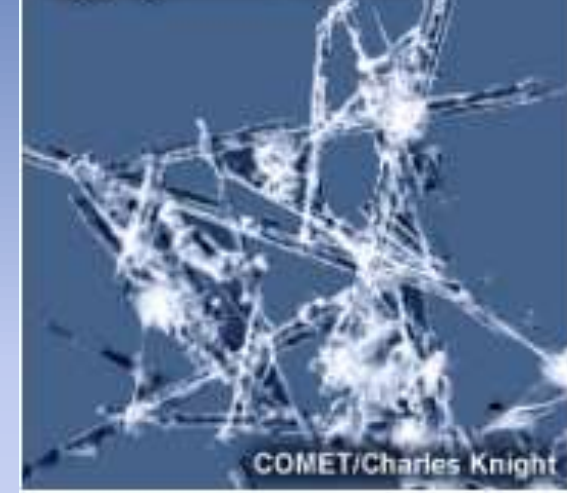


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Accretion/Riming

- Ice crystals grow as they fall/collide with supercooled water droplets
- Optimal in saturated layers of 0°C to -10°C
- Excessive riming eventually results in the formation of graupel or snow pellets
- Hail in summer grows by riming

Aggregated Ice Needles

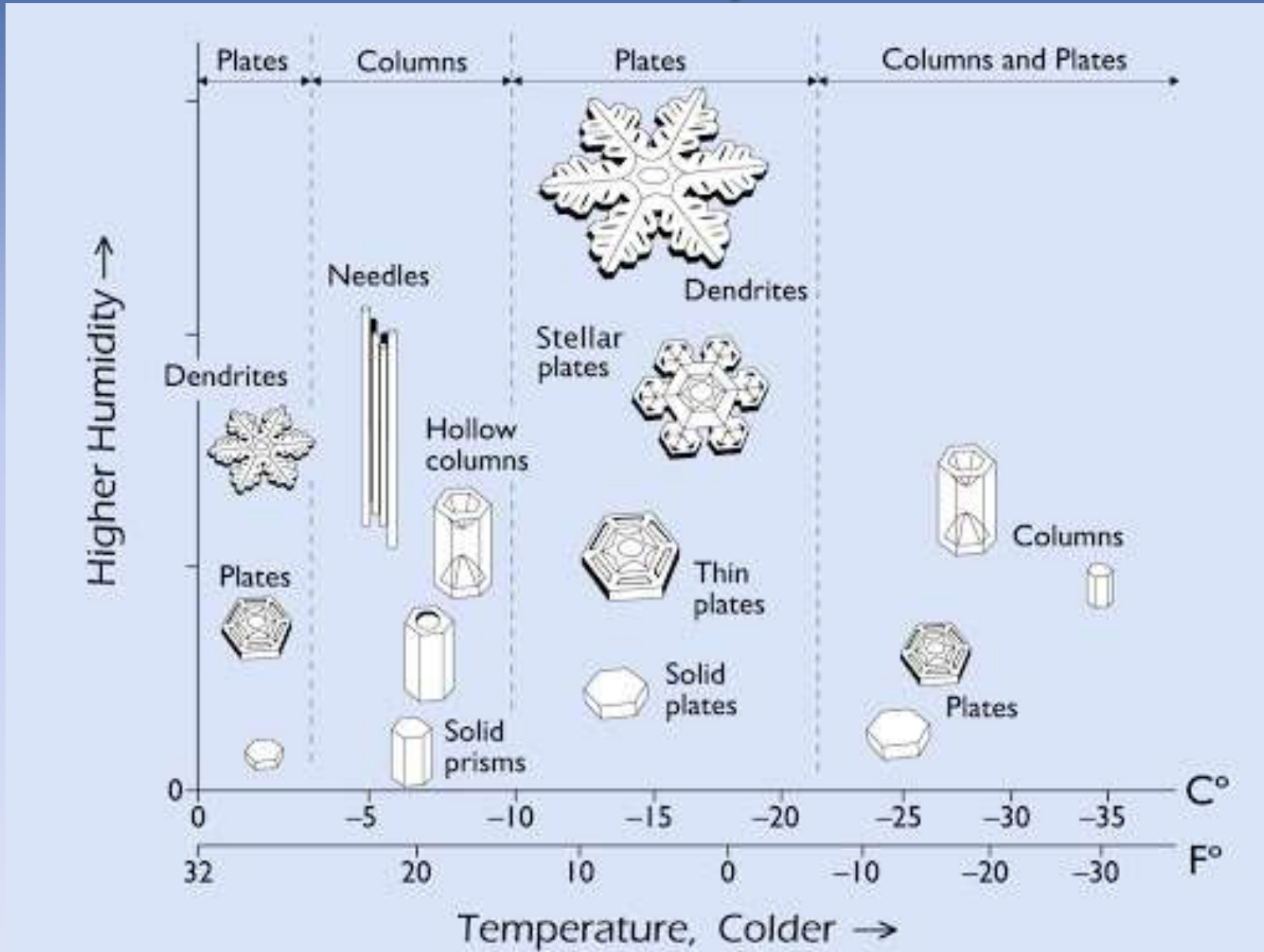


COMET/Charles Knight

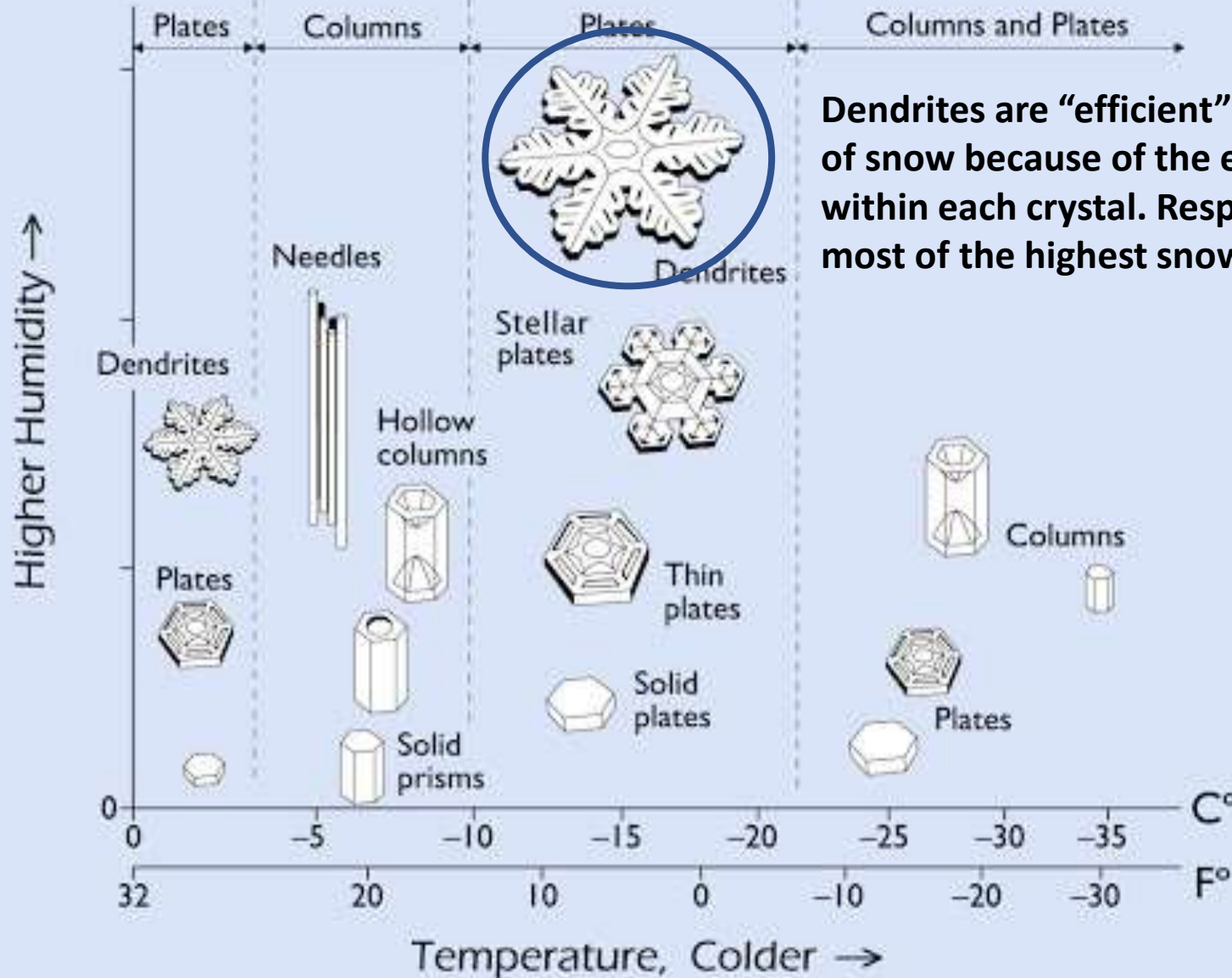
Aggregation

- Ice crystals stick to each other as they grow and collide
- Warmer portions of the cloud can add water droplets which acts like “glue” to aggregate more ice crystals
- Maximizes at -5°C to 0°C

Snow Crystals



Snow Crystals



Dendrites are “efficient” accumulators of snow because of the extra “space” within each crystal. Responsible for most of the highest snow amounts!

Rain Only Events

- When there aren't any surface temperatures near or below freezing, the forecast focuses on all liquid (rain) amounts
- Lift, moisture, and instability (for thunderstorms) are considered for the forecast
 - Lift: fronts, low pressure systems, outflow boundaries, and topographic effects are all ways that moisture can be lifted to form clouds, and then precipitation
- Weather models generally do a good job with QPF on widespread (non thunderstorm) rain events
 - QPF = Quantitative Precipitation Forecast – fancy term for amount of liquid that the model forecasts reaching the surface
- But what about when temperatures are at or below freezing?

Snow Events

- When freezing rain or sleet (will be discussed later) have been ruled out, and the forecast is all snow, additional elements have to be considered:
 - **Snow Ratio** - This is simply the amount of liquid that would result if you melted the snow that accumulates. Can have a big impact on the amount of snow that accumulates at the surface!
 - **Lift in the cloud** – It's very important to know where the lift will be the strongest within the cloud, and the temperature/amount of moisture in that layer! Impacts cloud microphysics, and thus, snow crystal type/snow ratio
 - **Location of the weather system** – depending on your location, you could either be in a more/less favorable location for enhanced snow development and accumulation
 - **Type of snow crystals** – Yes, snow has different crystal shapes depending on temperature and moisture content, and can have impacts on the amount of snow that accumulates. Related to snow ratio/cloud microphysics

Snow Ratio

- A typical snow ratio that you may hear quite a bit is 10:1, or “10 to 1”
 - This means if 1 inch of snow occurs, there is 0.10” (one tenth of an inch) of liquid water is contained within the snow. If 10 inches of snow occurs, 1 inch of liquid water is contained within the snow, etc.
 - This snow ratio is only correct about 25% of the time
 - Observational studies have shown freshly fallen snow to have snow ratios of 3:1 all the way up to 100:1!
- Think of snow ratio as how “heavy” the snow is
 - 6:1 snow is heavy, wet snow. Very heavy and wet when shoveling!
 - 11:1 snow is around average for our area
 - 30:1 or higher snow is very light, usually you can brush it away with a broom or blows easily in the wind!

Snow Ratio

SNOW:RATIO

The percentage of water within a sample of snow is called "snow ratio". An old rule of thumb was that for every 10 inches of snow, there would be 1 inch of water (10:1).

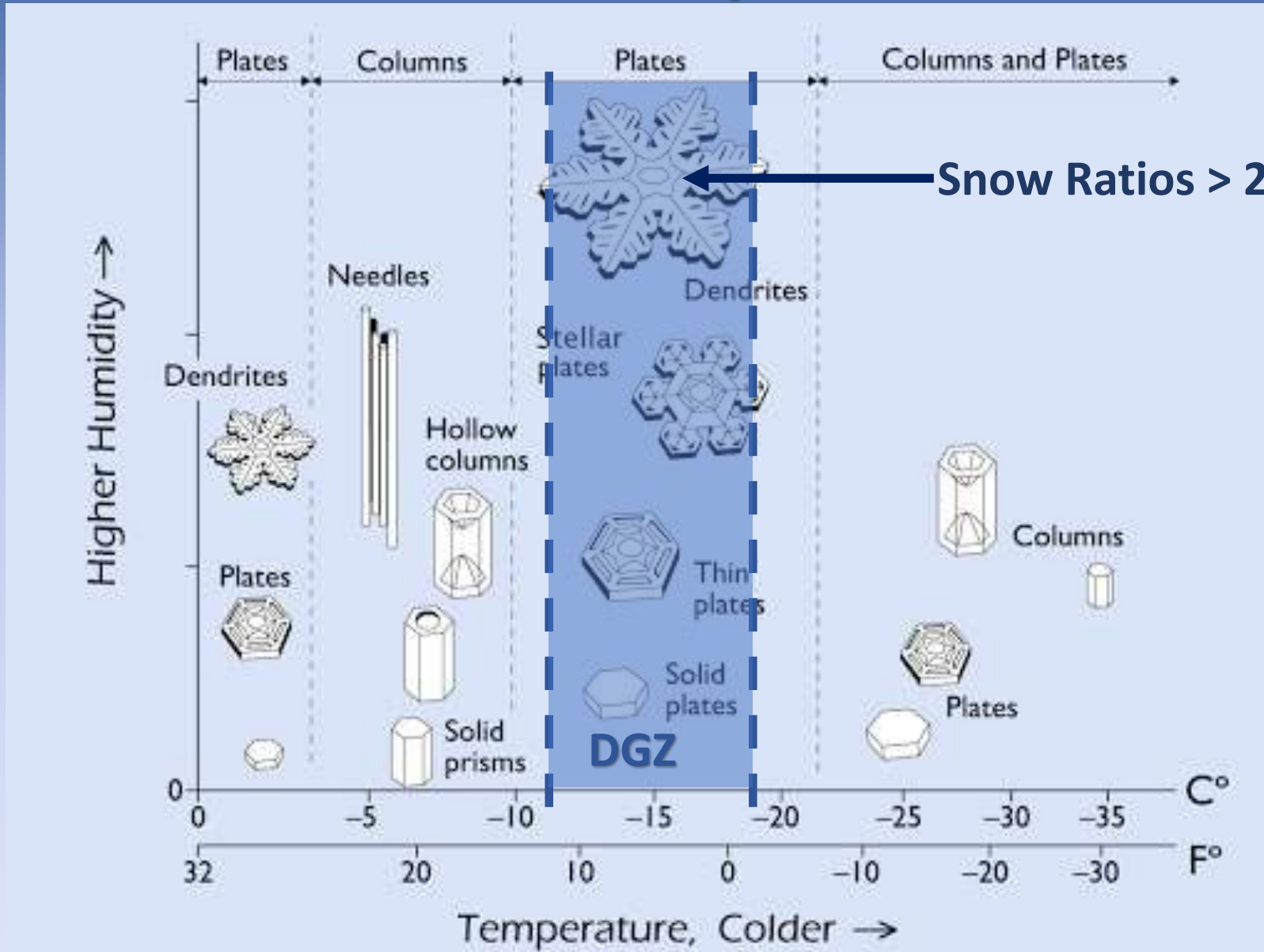
However, snow ratios can vary dramatically around the country and from event to event.

Variables that affect snow ratio

- Depth of the "warm" layer from the surface into the snow-producing cloud.
- Amount of ice in the snow-producing cloud.
- If its windy, snowflakes can fracture, losing their "lacy" structure.
- Deep cold leads to higher snow ratios.

Aggregate	Snow Ratio
Dendrite Aggregates <ul style="list-style-type: none">• Stellar crystals > 25• Needle assemblages• Rare	> 16
Mixed crystals <ul style="list-style-type: none">• Plates, columns, needles, and spatial dendrites• Lightly rimed stellar crystals or needle assemblages	9 – 16
Moderate to heavily rimed crystals and/or partially melted	3 – 8
Ice pellets and graupel	2 – 5

Snow Crystals



Snow Ratio



In-cloud ice crystal formation and aggregation into snowflakes

Snow Ratio



In-cloud ice crystal formation and aggregation into snowflakes

Sub-cloud sublimation and/or melting

Snow Ratio

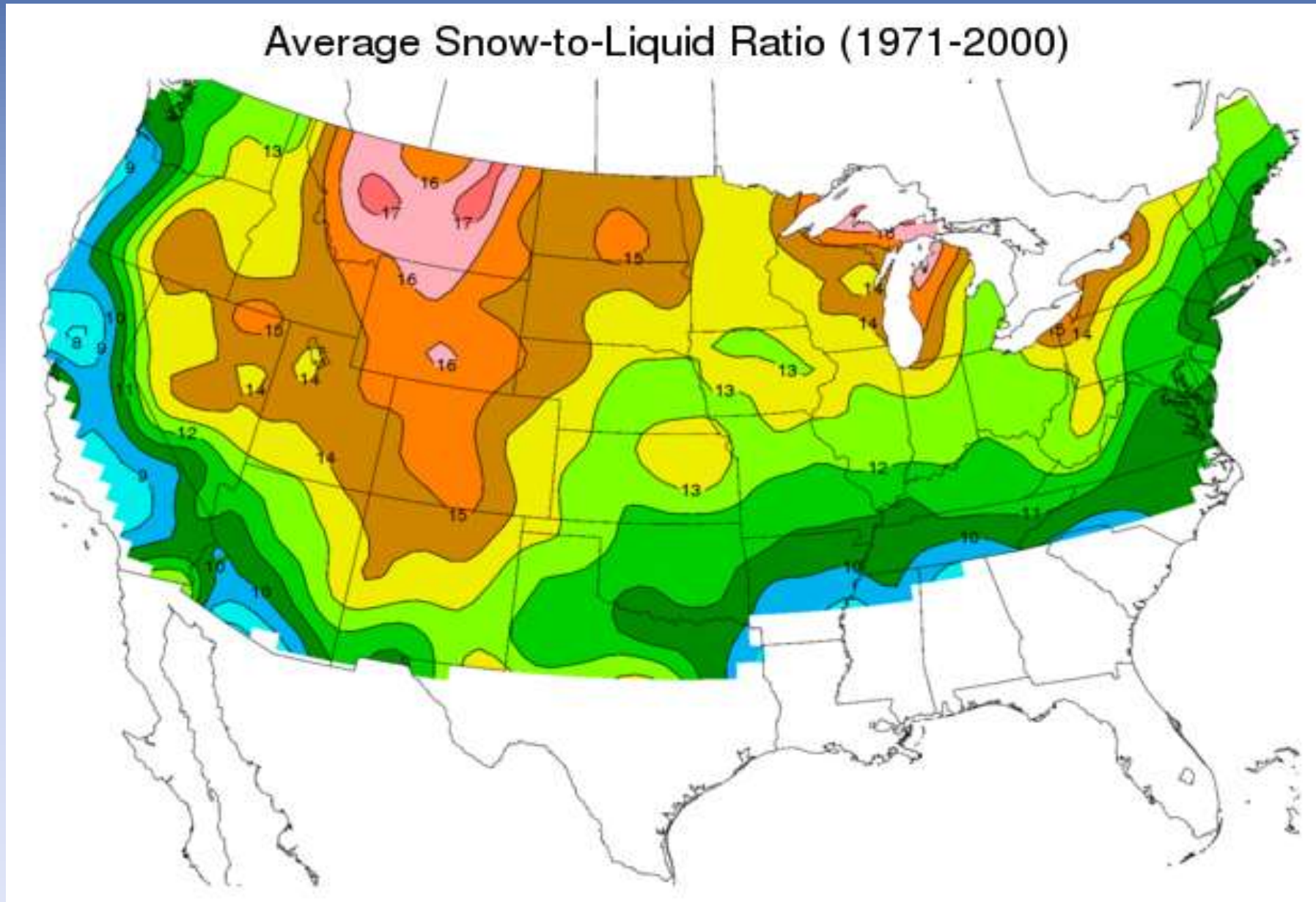


In-cloud ice crystal formation and aggregation into snowflakes

Sub-cloud sublimation and/or melting

Surface compaction via settling, sublimation, and/or melting

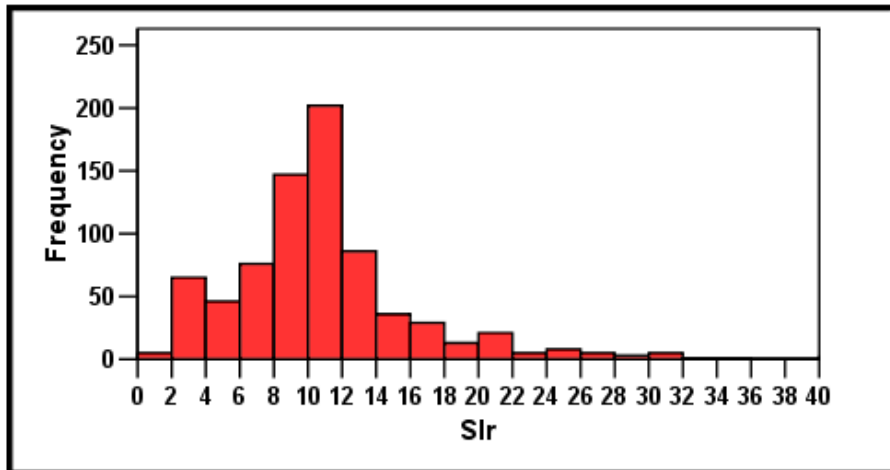
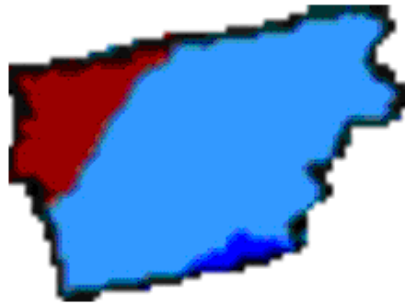
U.S. Average Snow Ratio



Snow Ratio

Nashville, TN

Avg SLR: 10.8
Standard Dev: 6.1
75th Percentile: 12.5
50th Percentile: 10.0
25th Percentile: 7.9

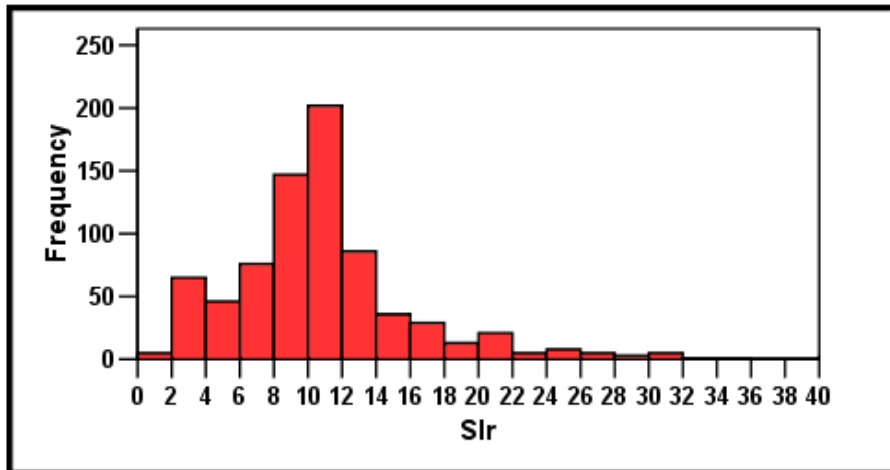
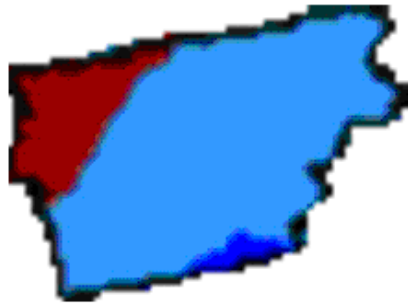


- SLR – Snow to Liquid Ratio, or Snow Ratio
- On average, Middle Tennessee sees snow ratios around 11:1
- However, observed snow ratios have been as high as 32:1! (Very dry, light snow)

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- On average, Middle Tennessee sees snow ratios around 11:1
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But what does all of this mean? How does this impact snowfall forecasts?!

Snow Ratio

- Lets say we have all weather models saying Nashville will get 1 inch of QPF (or 1 inch of liquid rain equivalent)
- If this were an event that was all rain, we would be confident in saying Nashville will get around 1 inch of rain in our forecast
- However, assuming all of the QPF will fall as snow, and only considering snow ratio (for now), we forecast a very wet 8:1 snow ratio

1 inch of liquid QPF x 8:1 snow ratio = 8 inches of snow

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- UH OH! There was some additional strong lift in the cloud layer that produces larger and lighter dendrite snow crystals, and produced a surface snow ratio of 11:1!

1 inch of liquid QPF x 11:1 snow ratio = 11 inches of snow

Snow Ratio

- In our example, lets say some **rain** was going to start off the event, with the transition to all **snow** halfway through the event
- Just this additional change can drastically alter the snow forecast

0.5” of liquid QPF x 11:1 snow ratio = 5.5 inches of snow

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- If rain lasts longer, less moisture (and QPF) will be attributed to snow

0.25" of liquid QPF x 11:1 snow ratio = 2.8 inches of snow

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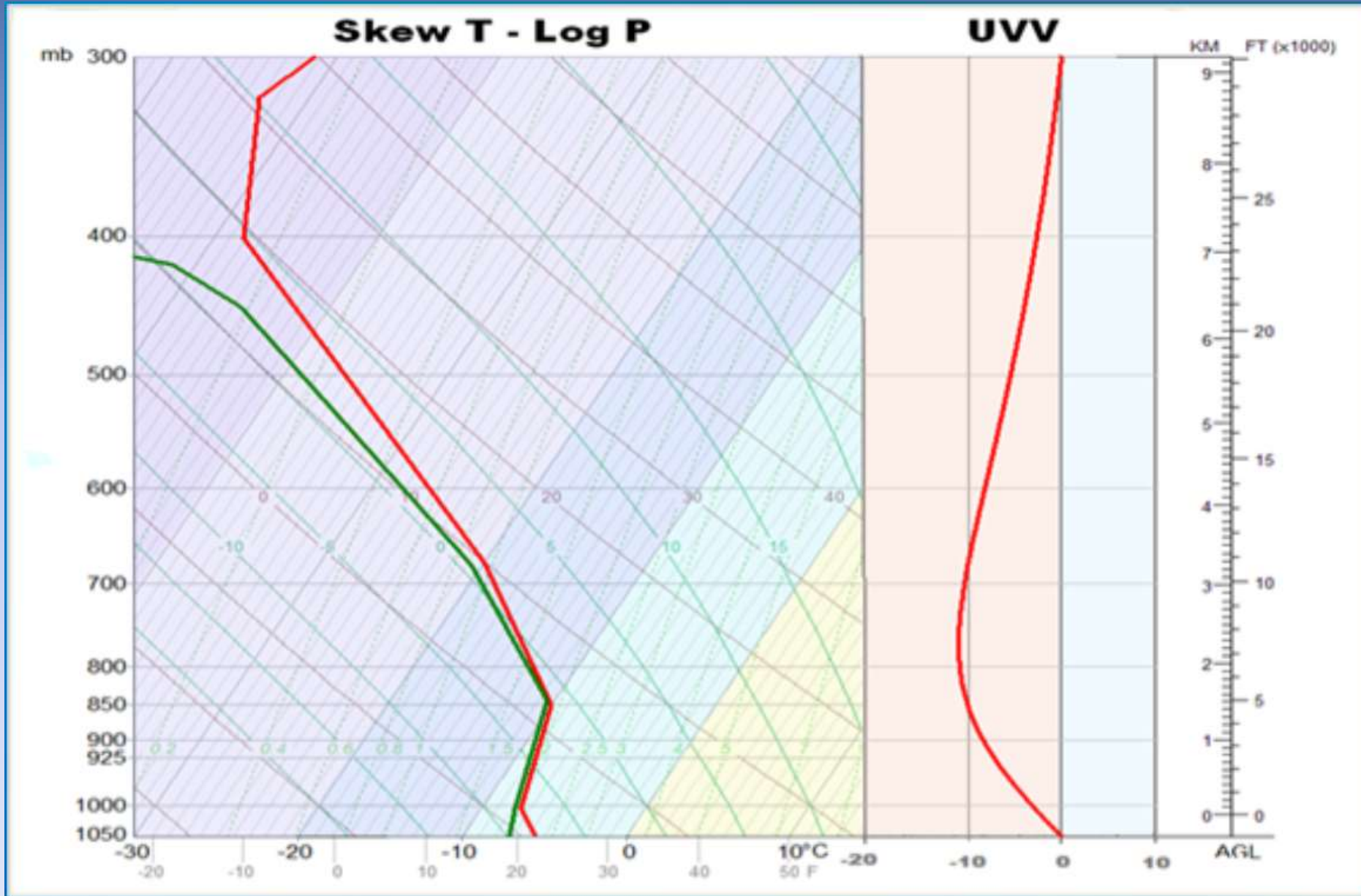
0.75" of liquid QPF x 11:1 snow ratio = 8.3 inches of snow

(***of course, the snow ratio would likely not remain the same if the transition time from rain to snow changes, adding another variable to the difficulty of snowfall forecasting***)

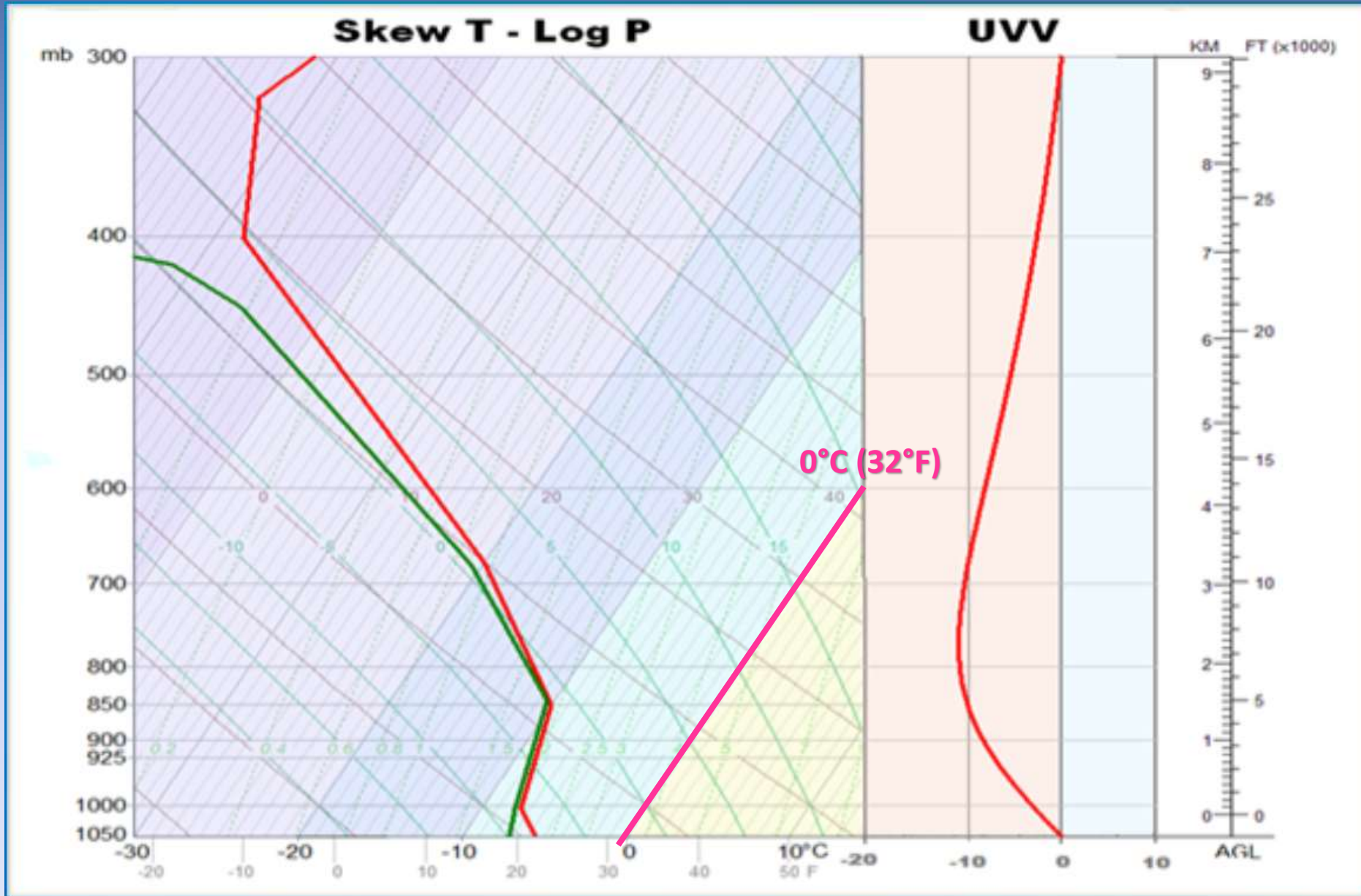
Some Other Factors that Impact Snow Forecasting

- **Temperature of the surface**
 - If the air temperature is below freezing, but the surface is above freezing, some of the early snowfall will melt, which will lower the snow totals
- **Near surface winds**
 - Stronger winds at the surface (or even below the cloud layers) acts to dry out the snow and/or break up snow crystals, which can increase the snow ratio and change snow totals
- **Timing**
 - If snow starts/ends earlier, or starts/ends later, snow totals will be affected. This includes the overall event time as well as any transitions to/from other precip types (rain, freezing rain, sleet, etc)
- **Surface compaction/melting**
 - Heavier snow (lower snow ratios below 12:1) compact on the surface as they accumulate. So if someone measured snow every hour, they would get a higher snow total than someone who just measured when it stops snowing
- **Dry Air Entrainment**
 - Dry air can disrupt snowfall development within cloud layers, evaporate snow beneath the clouds, or evaporate snow near the surface

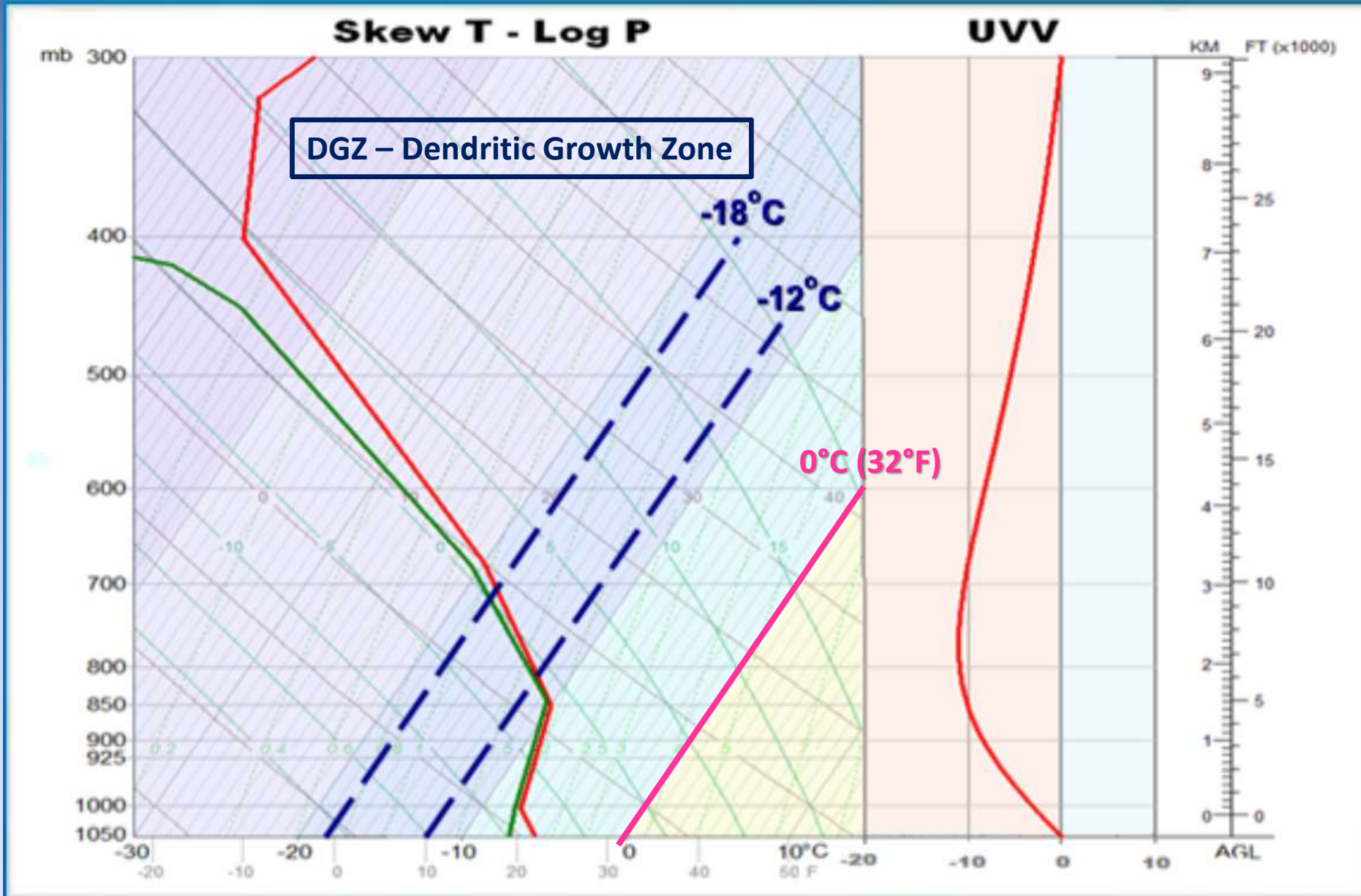
Lift



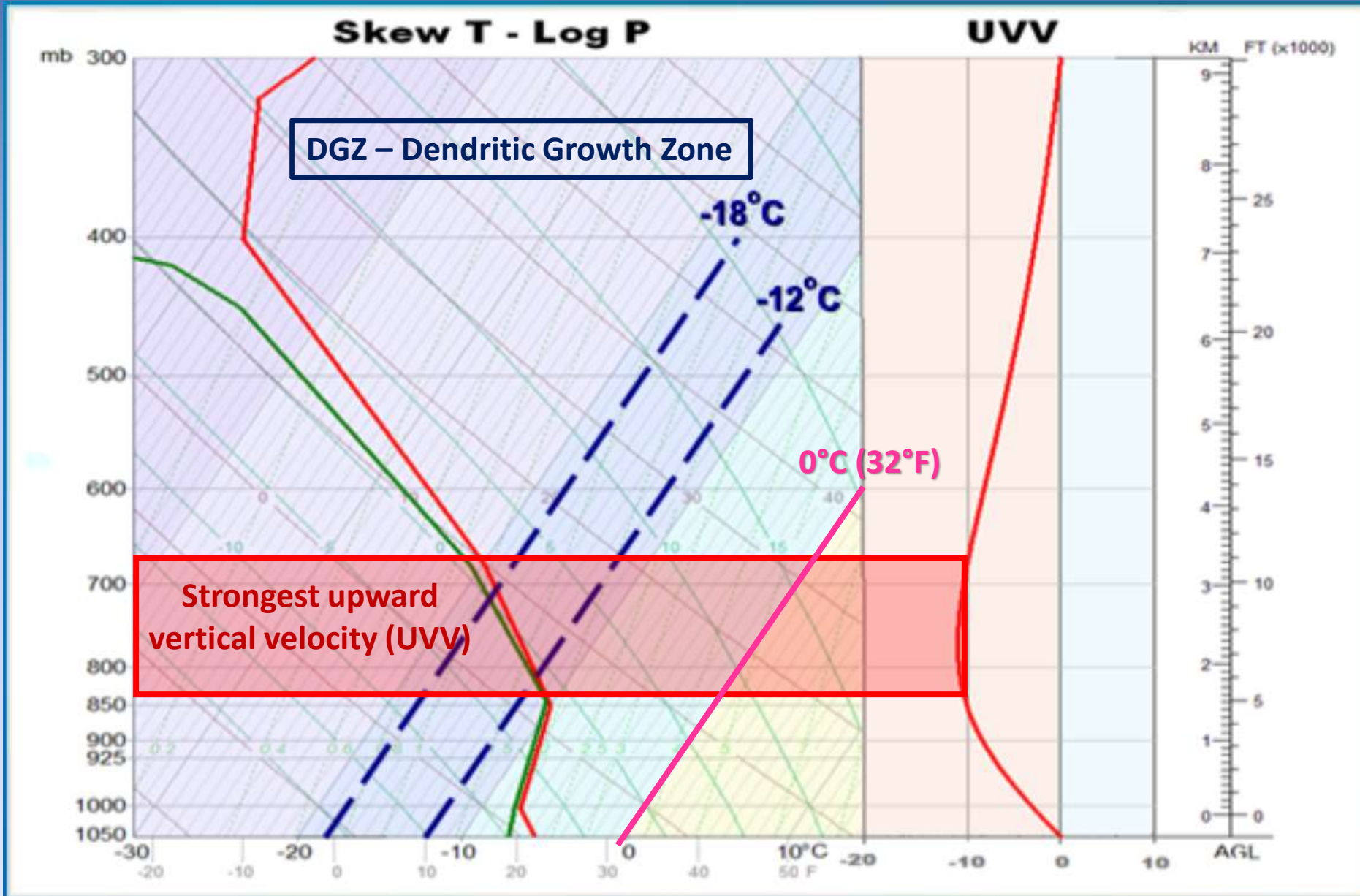
Lift



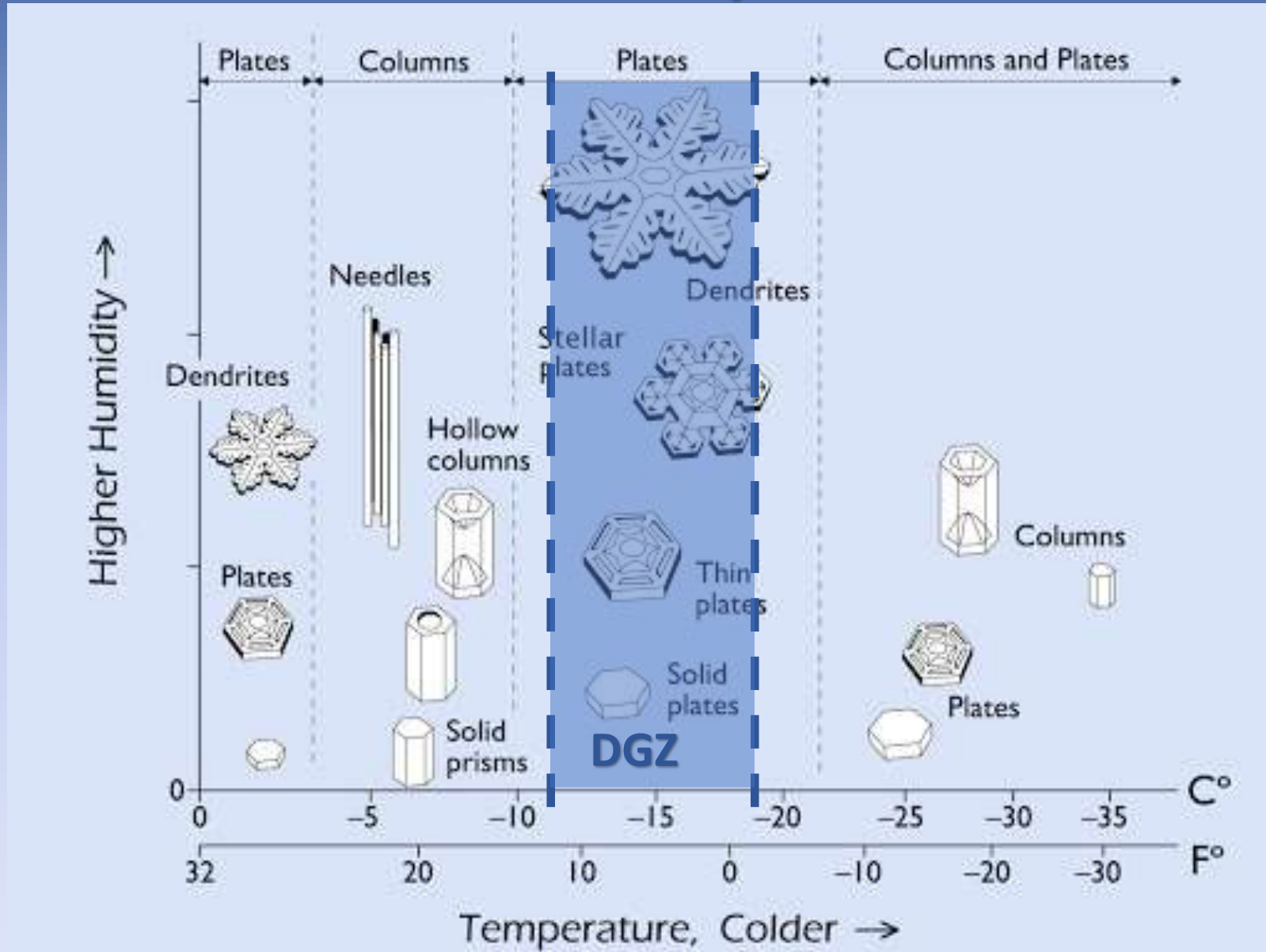
Lift



Lift



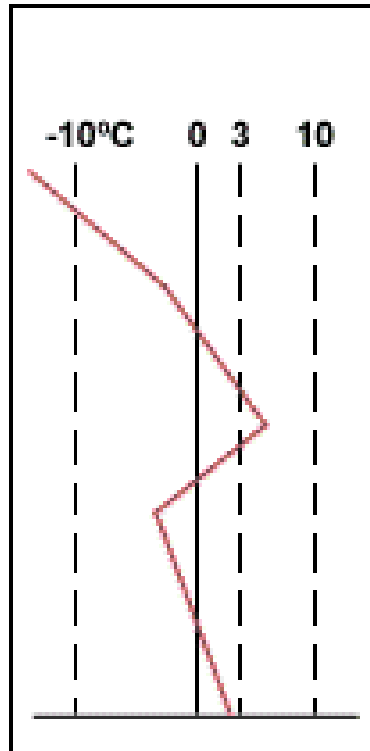
Snow Crystals



What About Other Precip Types?

Rain

Precipitation Type and Temperature Profile: Rain



Ice Producing Layer:
 $T < -10^{\circ}\text{C}$, producing ice

Warm Layer:
if $1^{\circ}\text{C} < T < 3^{\circ}\text{C}$ partial melting
if $T > 3^{\circ}\text{C}$ total melting

Near Surface Cool Layer:
if $T_{\text{surface}} \gg 0^{\circ}\text{C}$ melting whether
entering as ice or mix

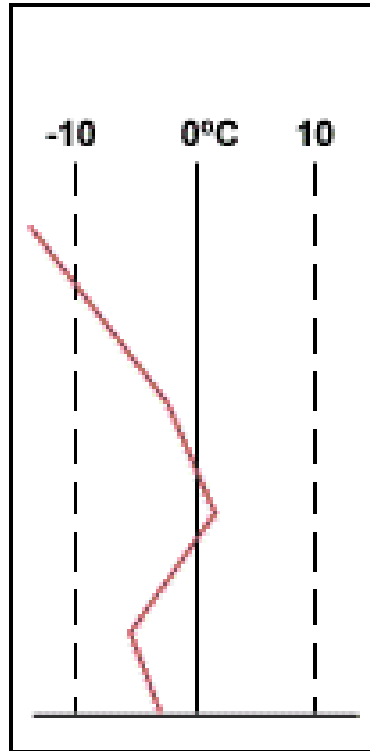
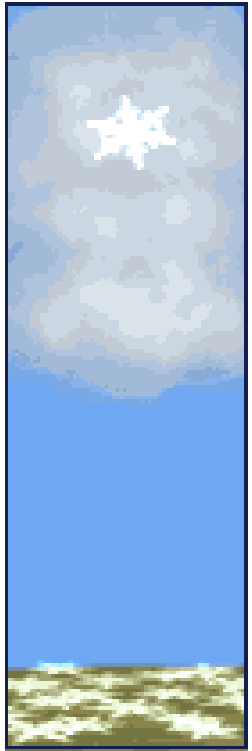
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- If the majority of the lowest 5000 ft is above freezing (and above 3°C) the surface precip type will be rain
- Even if there is another near surface cool layer, the warm surface will melt any potential ice/mix

What About Other Precip Types?

Snow

Precipitation Type and Temperature Profile: Snow



Ice Producing Layer:
 $T < -10^{\circ}\text{C}$, producing ice

Warm Layer:
 $T < 1^{\circ}\text{C}$ or not present

Near Surface Cold Layer:
 $T < 1^{\circ}\text{C}$

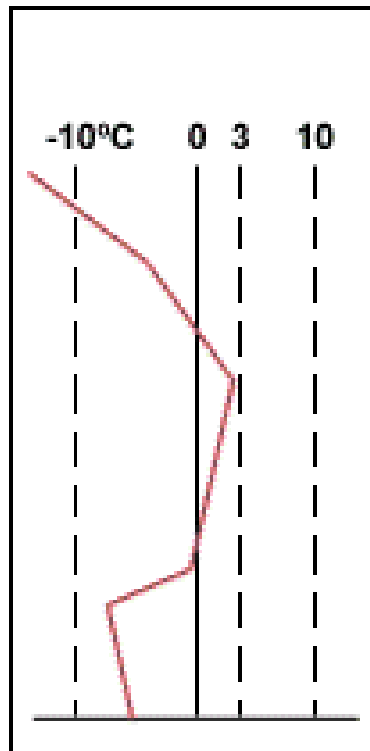
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- With most of the atmosphere below freezing, the likely surface precip type will be snow
- Unless the saturated (high relative humidity) layer is above -10°C , which will likely be freezing rain

What About Other Precip Types?

Sleet

Precipitation Type and Temperature Profile: Ice Pellets/Sleet



Ice Producing Layer:
 $T < -10^{\circ}\text{C}$, producing ice

Warm Layer:
 $1^{\circ}\text{C} < T < 3^{\circ}\text{C}$ partial melting with potential mix

Near Surface Cold Layer:
if $T < 0^{\circ}\text{C}$ refreeze partially melted
if $T < -6^{\circ}\text{C}$ for > 750 m, ice pellets from liquid

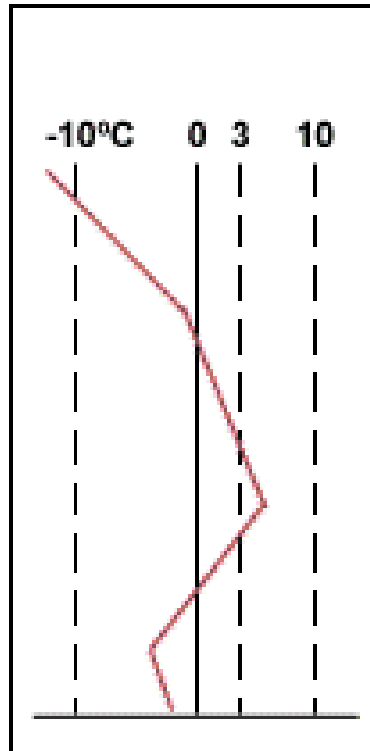
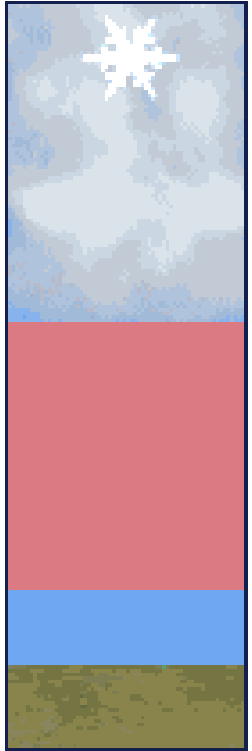
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- Precip forms in cloud layers less than -10°C , likely ice and snow
- Snow falls into a warm layer above 1°C and less than 3°C causing partial melting and/or mixed precip
- If the near surface layer is cold and deep enough (more than 2000 ft), partially melted snow and/or rain will re-freeze into sleet

What About Other Precip Types?

Freezing Rain

Precipitation Type and Temperature Profile: Freezing Rain



Ice Producing Layer:
 $T < -10^{\circ}\text{C}$, producing ice

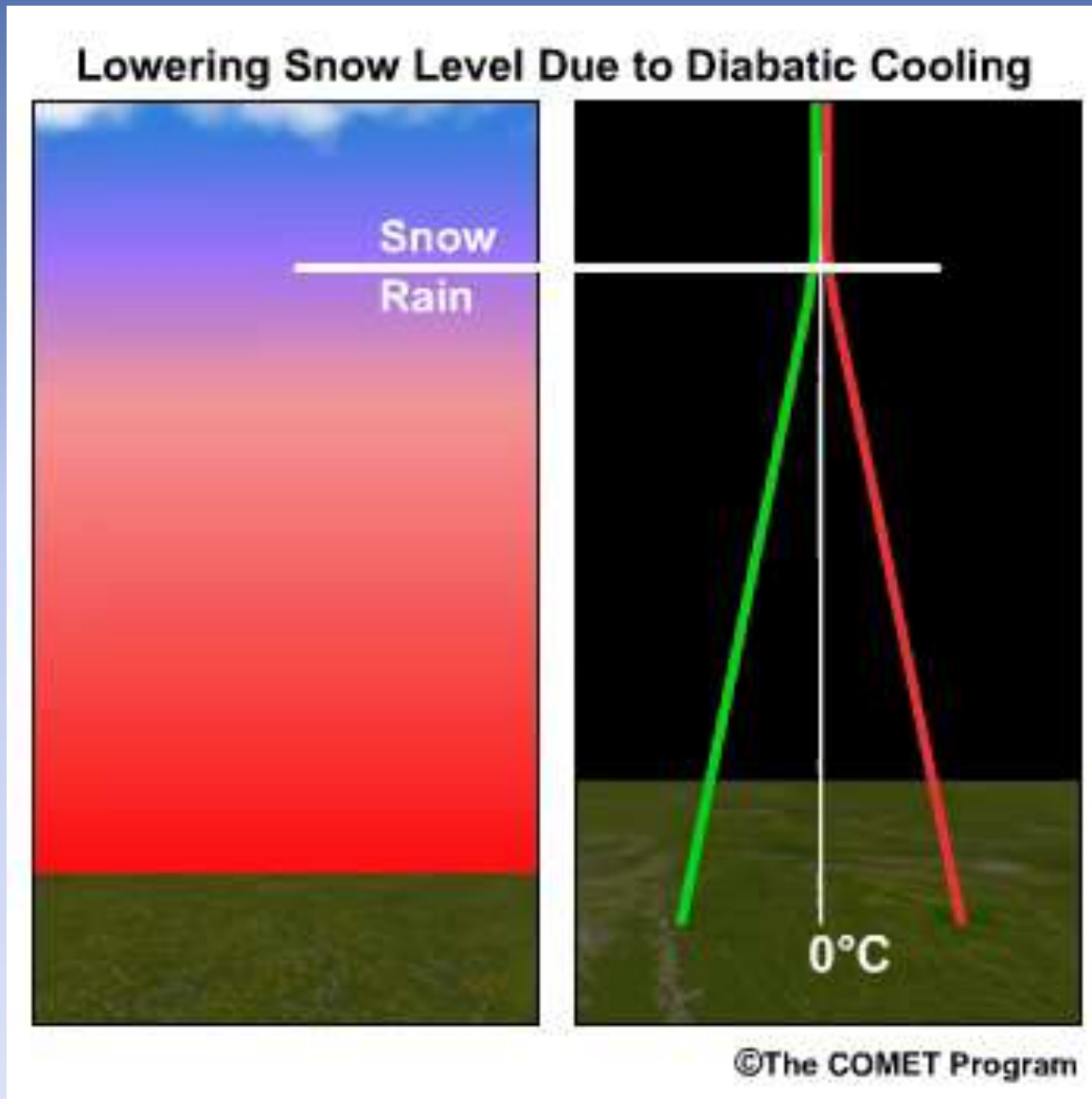
Warm Layer:
 $T > 3^{\circ}\text{C}$ melting all ice

Near Surface Cold Layer:
if $-6^{\circ}\text{C} < T < 0^{\circ}\text{C}$ for $< 750\text{ m}$
if $T < -6^{\circ}\text{C}$ for $> 750\text{ m}$, ice pellets
can form

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- Precip forms in cloud layers less than -10°C , likely ice and snow
- Snow falls into a warm layer above 3°C causing complete melting to all rain
- Near surface is just below freezing (less than 2000 ft: not deep enough of a cold layer for sleet) and surface below freezing, freezing rain will result

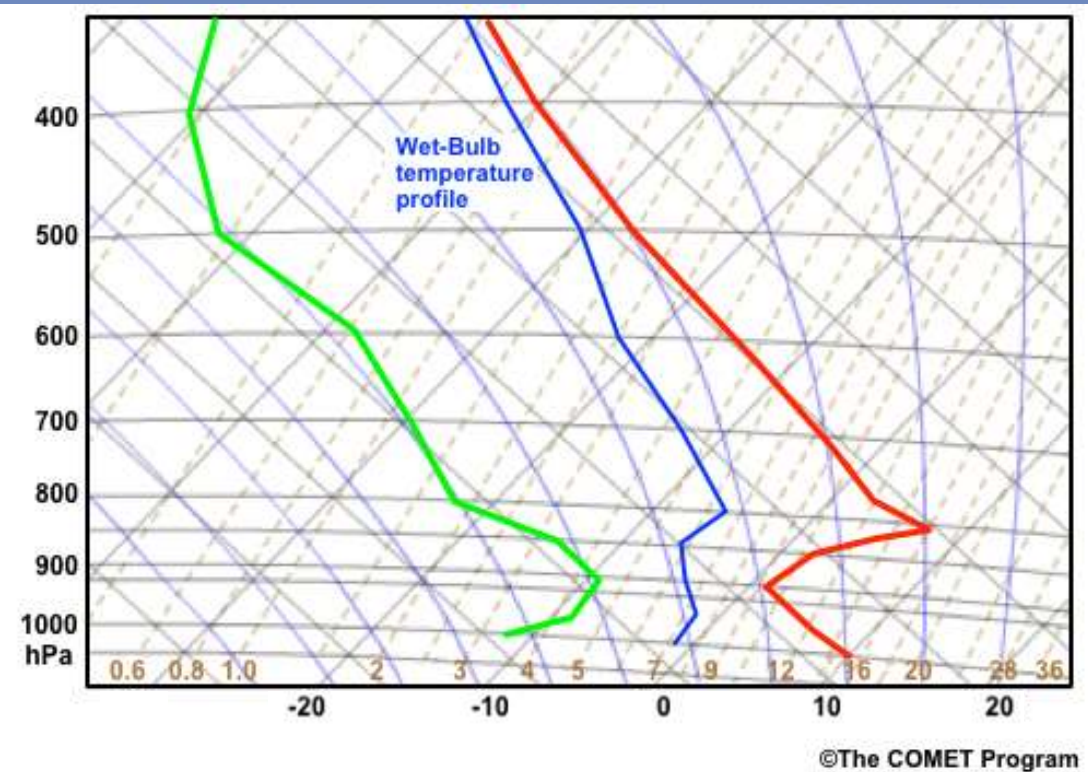
What About Other Precip Types?



- Sometimes, the near surface air is too dry for any precipitation to reach the surface
- As precipitation falls, it evaporates, which cools the atmosphere
- This is known as diabatic cooling. Latent heat energy from the air changes precipitation to water vapor, increasing the humidity
- Meteorologists sometimes refer to this as the “wet bulb effect”
- When this occurs, the surface temperature can be above freezing, yet you can see sleet, flurries, snow, etc

What About Other Precip Types?

Wet Bulb Temperature

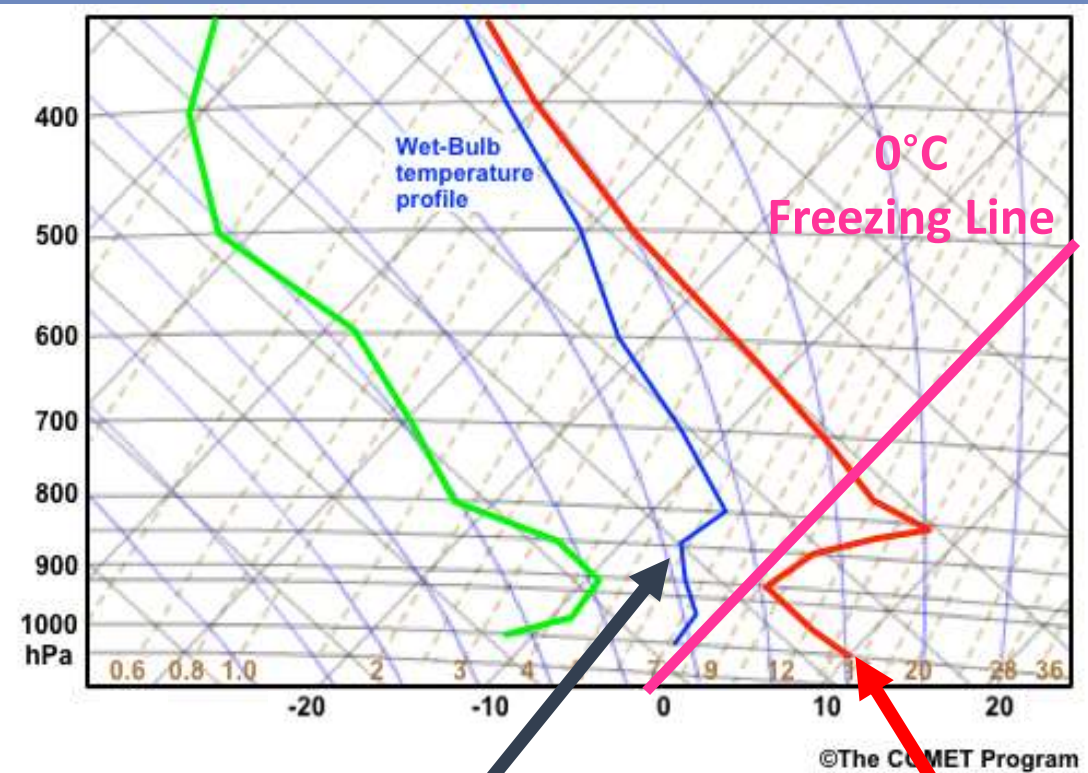


- Simplest definition: the lowest temperature that can be reached under current conditions by evaporation of water **only**
- Actual temperature is the dry bulb temperature
- Water can only evaporate if the air around it can absorb more water. So at 100% humidity, the air is completely saturated, so the wet bulb temperature = actual temperature
- This somewhat explains “it’s a dry heat”... the drier the air, the faster the evaporation, and the cooler you feel when your sweat evaporates
- But when relative humidity is 100%, the air can not hold any more moisture, and cooling by sweating/evaporation is not possible

What About Other Precip Types?

Wet Bulb Temperature

- So, if the wet bulb zero (32°F) height is at or less than 1,500 feet off the surface, frozen precipitation (snow/sleet/graupel) can occur even if the actual surface temperature is above 32°F!
- The wet bulb temperature being below 32°F could be one of the factors your car thermometer has a temperature in the mid to upper 30s, yet its snowing
- Out west, where it can be much drier, snow/sleet/graupel can occur with temps as high as 50°F due to a cold wet bulb temperature!



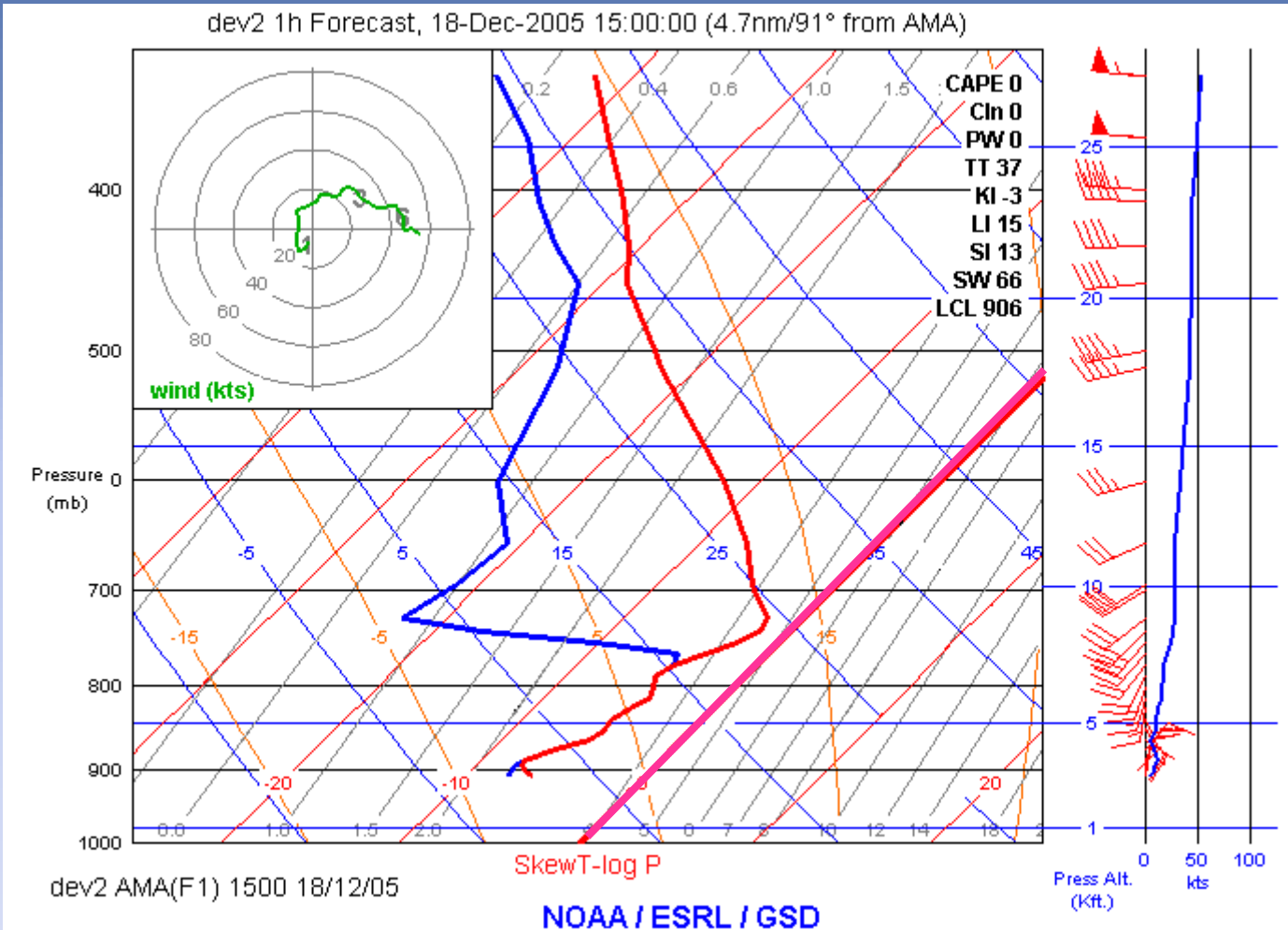
Wet bulb temp profile
entirely below freezing

Surface temp 50°F (10°C)

What About Other Precip Types?

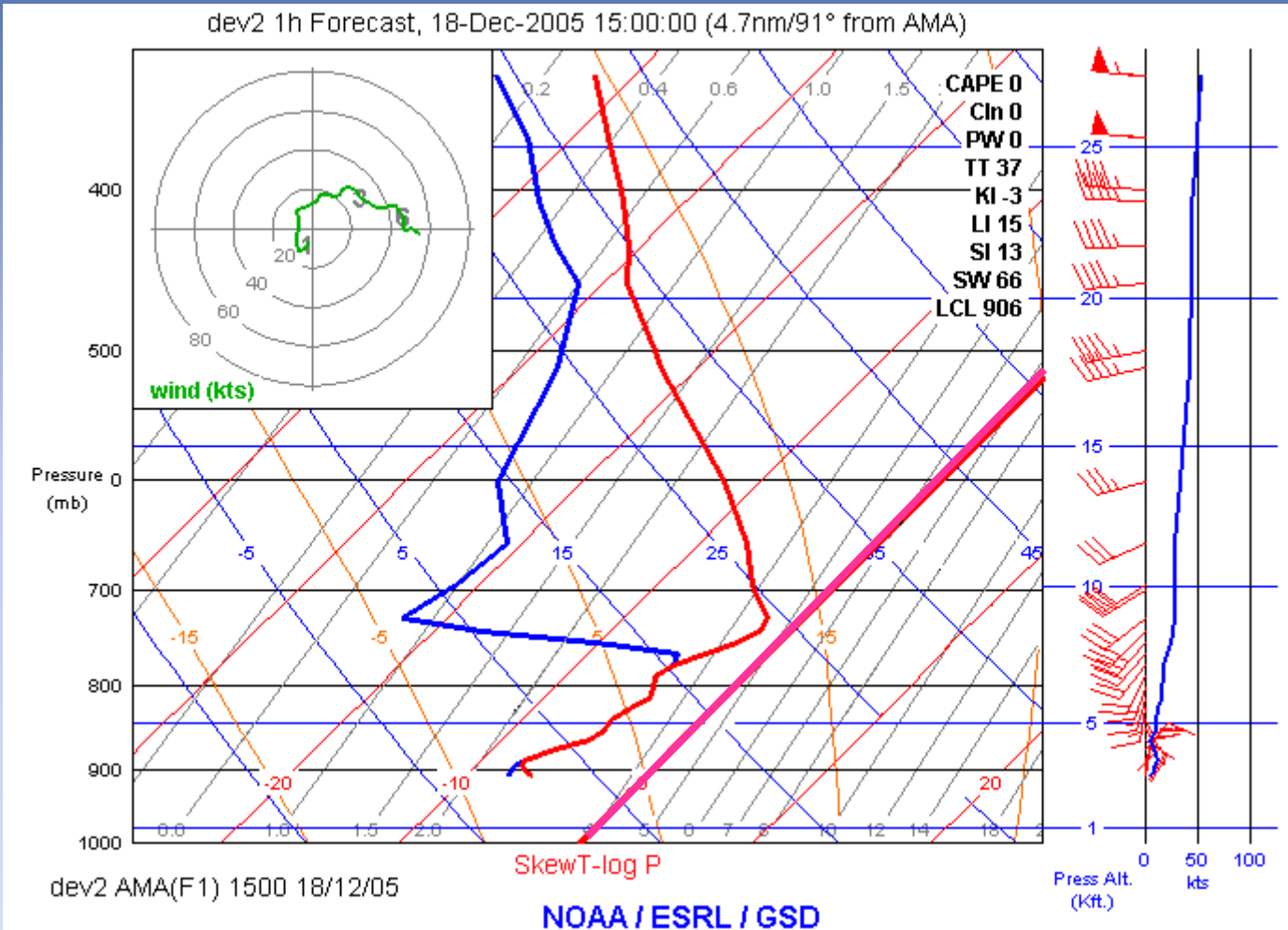
- **What does all of this mean?** Variations in just a *few degrees* could completely change the forecast!
- Not only a few degrees at the surface, but a few degrees anywhere in the lowest ~3000 ft could drastically change the surface precipitation type
- Also changes in the relative humidity in the lowest ~3000 ft can change the forecast precipitation type, as well as accumulating snow amounts
- Wet bulb temps below 32°F (0°C) at 1500 ft and lower can result in snow/sleet/graupel despite actual surface temperatures above freezing
- With rain events in the summer, there's zero chance of any mixed precipitation, so forecasts are easier when compared to winter events (no forecast is ever easy!). A few degrees here and there when its 70 to 90 degrees doesn't matter much. A few degrees when its in the low to mid 30s can mean all snow, all rain, or anything in between!

Guess the Precip!



- Entire temperature profile below freezing
- 100% RH near the surface up to ~7500 ft
- What's the surface precip?!

Guess the Precip!

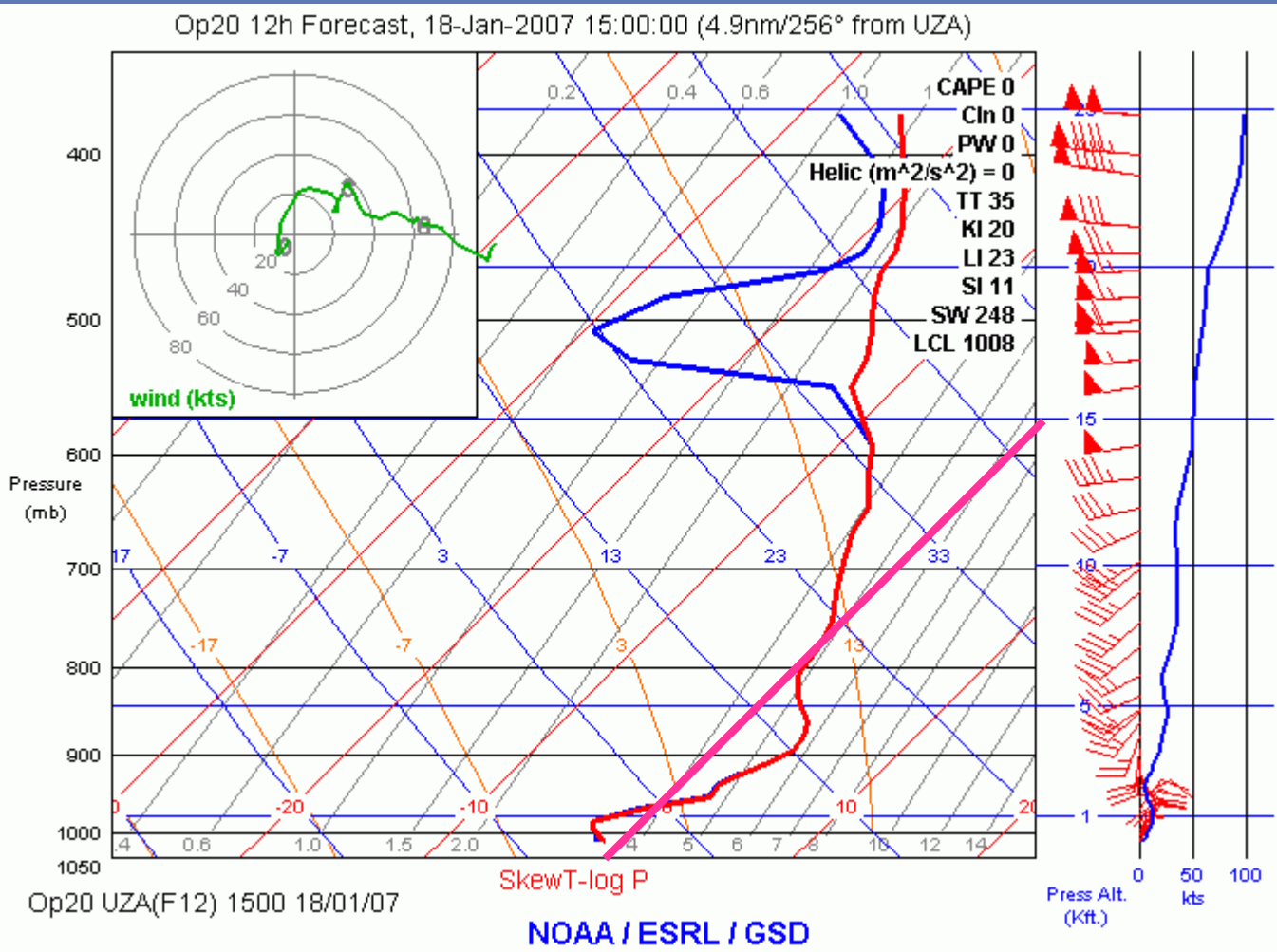


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FREEZING RAIN!

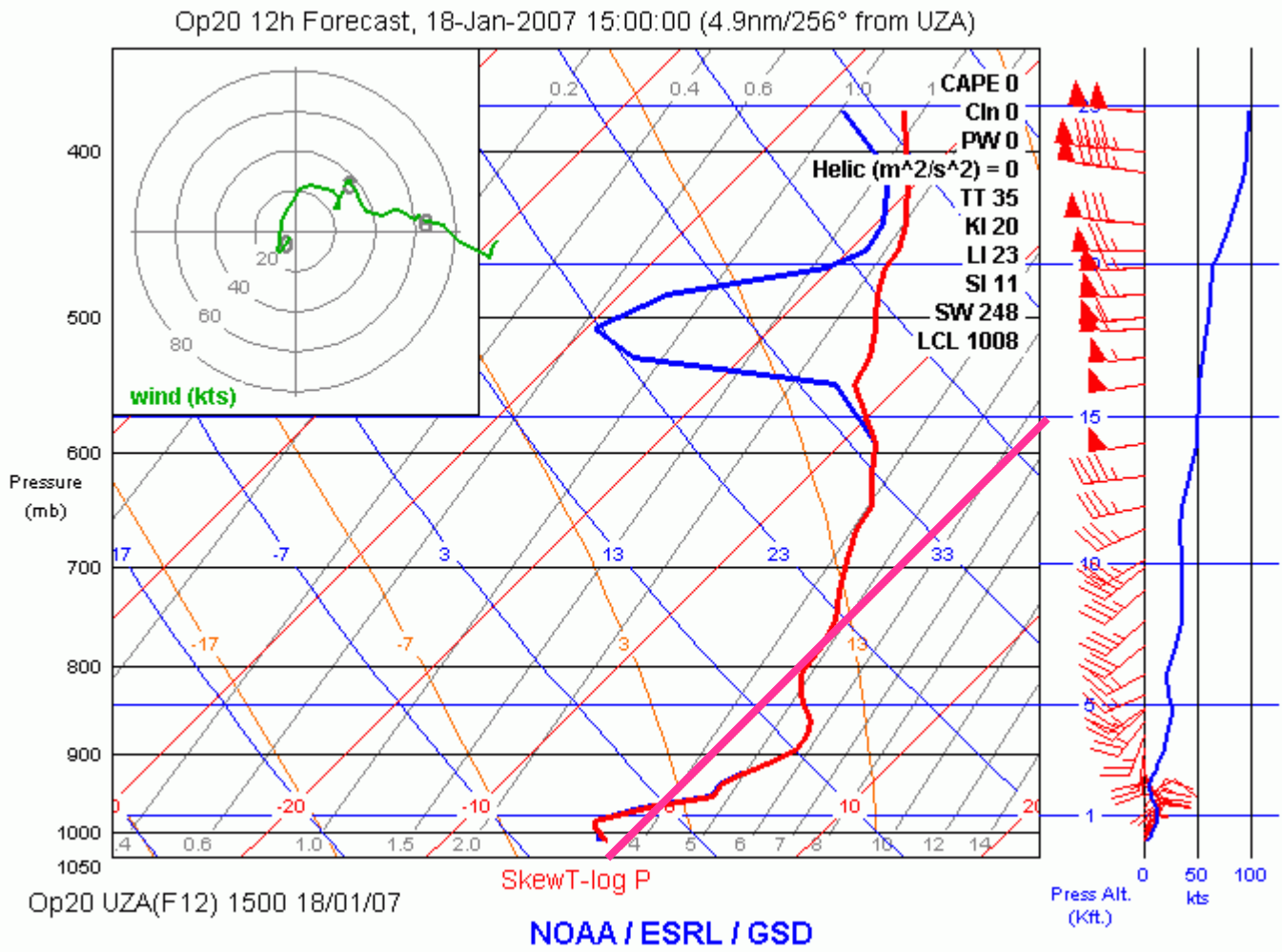
- No saturated layer colder than -10°C
- Remember that above -10°C there's a 60% chance of ice in the cloud
- Coldest temp in cloud layer: -8°C , ~40% chance of ice in the cloud

Guess the Precip!



- Deep warm saturated layer from 1500 ft to 6000 ft
- Lowest 1500 ft below freezing
- What's the surface precip?!

Guess the Precip!

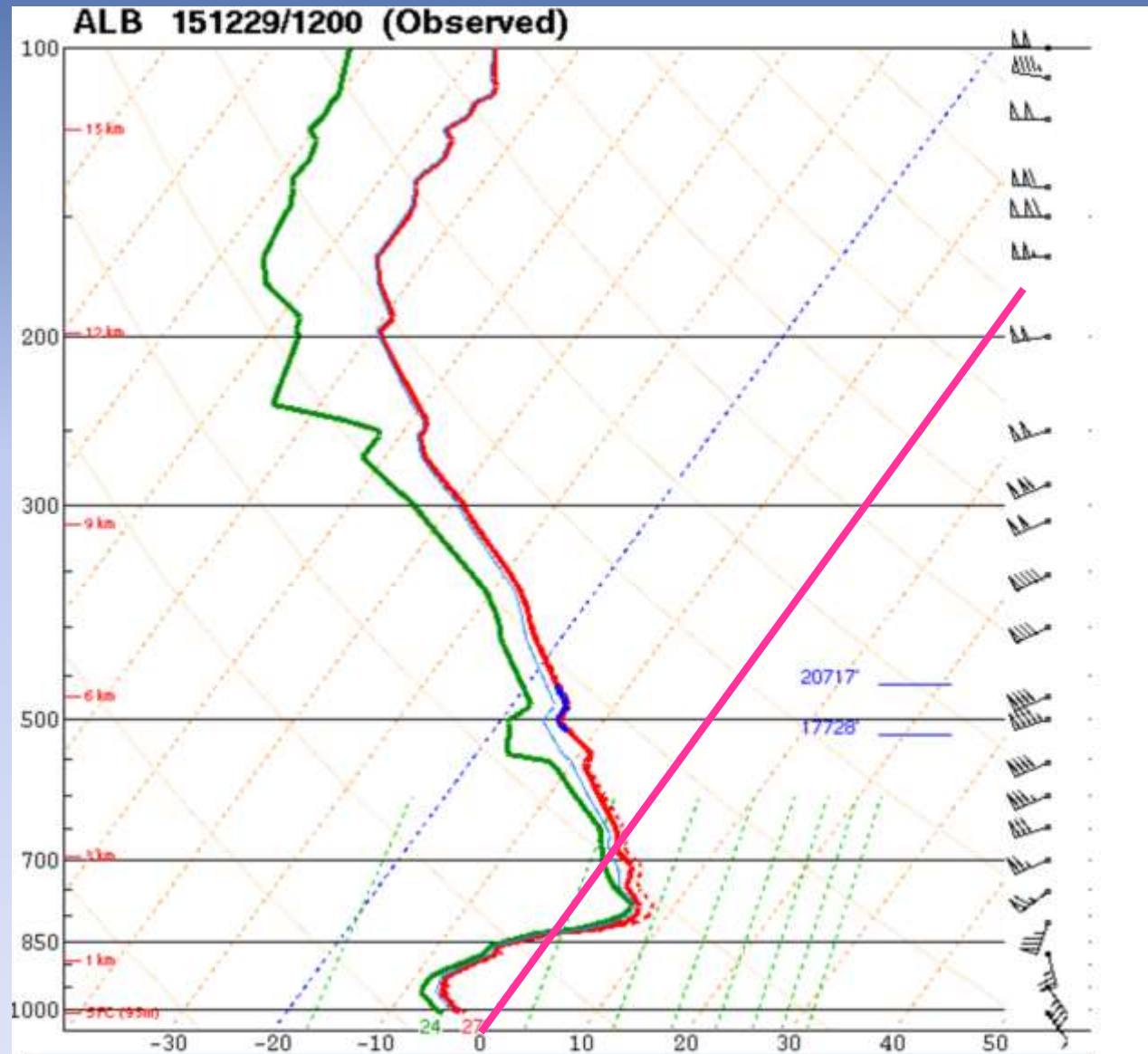


- Deep warm saturated layer from 1500 ft to 6000 ft
- Lowest 1500 ft below freezing
- What's the surface precip?!

FREEZING RAIN!

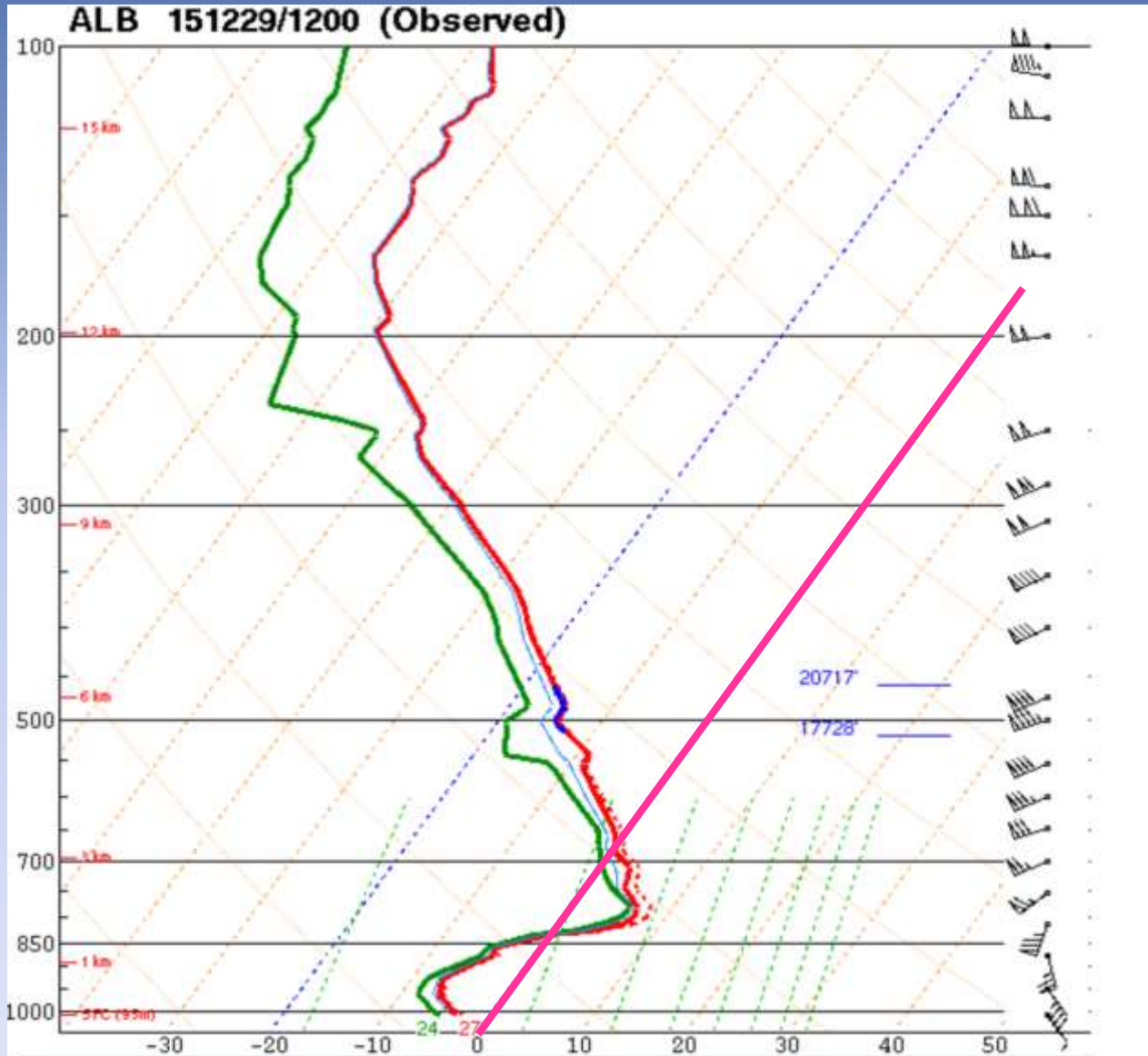
- Below 32°F (0°C) layer less than 2000 ft, and warmer than -6°C

Guess the Precip!



- Warm layer from around 4000 ft to 10,000 ft
- Lowest 4000 ft below freezing
- What's the surface precip?!

Guess the Precip!

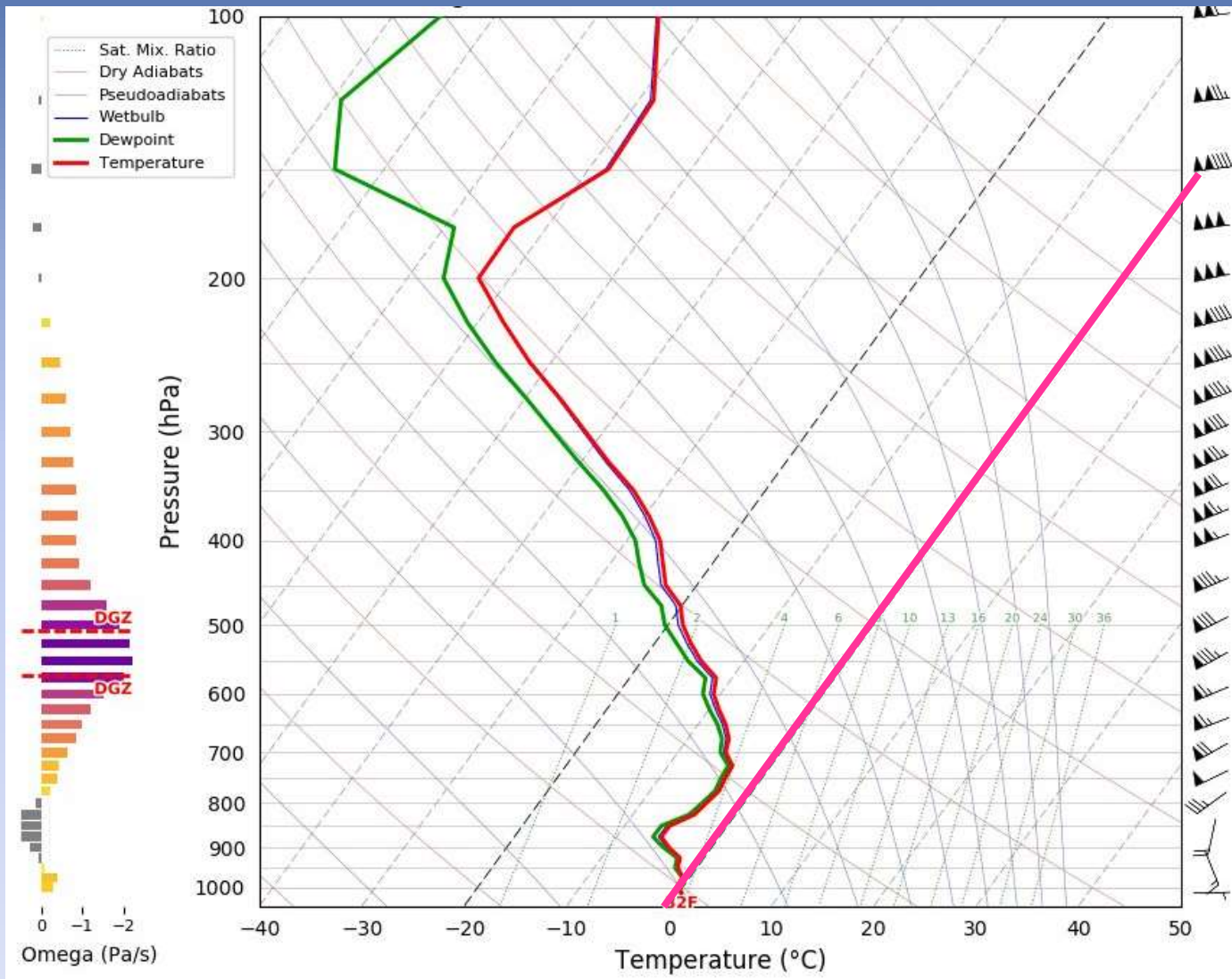


- Warm layer from around 4000 ft to 10,000 ft
- Lowest 4000 ft below freezing
- What's the surface precip?!

SLEET!

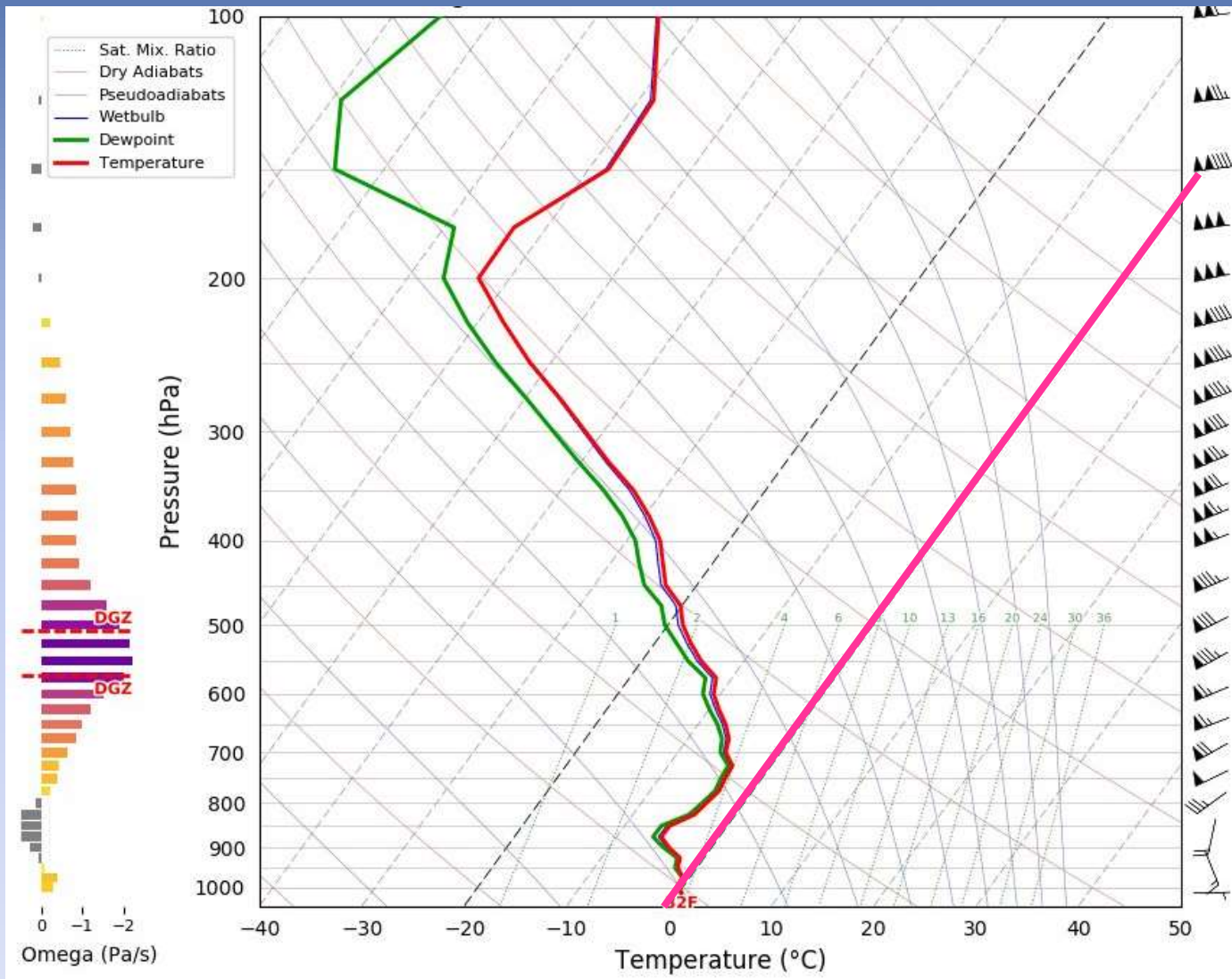
- Near surface cold layer well over 2000 ft
- Deep warm layer warm enough to melt ice crystals from aloft

Guess the Precip!



- Entire temperature profile below freezing
- Saturated from the surface through most of the atmosphere
- Strong vertical motion in the -12°C to -18°C saturated layer
- What's the surface precip?!

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HEAVY SNOW!

- Strongest vertical motion is in the DGZ (dendritic growth zone)
- Saturated and below freezing
- Very strong winds aloft (jet stream overhead)
- All support a heavy snow outcome

SNOW:RATIO

The percentage of water within a sample of snow is called "snow ratio". An old rule of thumb was that for every 10 inches of snow, there would be 1 inch of water (10:1).

However, snow ratios can vary dramatically around the country and from event to event.

Variables that affect snow ratio

- Depth of the "warm" layer from the surface into the snow-producing cloud.
- Amount of ice in the snow-producing cloud.
- If its windy, snowflakes can fracture, losing their "lacy" structure.
- Deep cold leads to higher snow ratios.

Questions?

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