Snow Microphysics and the Top-Down Approach to Forecasting Winter Weather Precipitation Type

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Snow Microphysics and the Top-Down Approach to Forecasting Winter Weather Precipitation Type

Why is Snow Microphysics Important?

- Numerical Prediction Models better forecast areas of large scale forcing which lead to precipitation, then they can forecast actual "quantitative precipitation amounts" over a given area.
- During big snowfalls, much of the heavy snow falls in a short time frame. Forecasting these brief periods of snowfall is very important for both short term considerations and total storm snowfall.
- There is considerable variability to the character of snow from event to event and during an event.
- Snowflake size and type has considerable impact on overall snow accumulation rate and visibility… which then greatly affects travel and safety.

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Why is Snow Microphysics Important?

- The character of snowfall is also related to variations in lift, moisture content, and vertical temperature profile.
- Put it all together and you'll find that:

The relationship between vertical motion and snow microphysics greatly impacts snowfall efficiency – or how much snow can fall from a given moisture and temperature environment!

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Cloud Droplets and Ice Nucleation

- All "sub-freezing" clouds contain "super-cooled" water droplets that can exist at temperatures as cold as – 40 C (- 40 F) without freezing, when in the absence of "ice nuclei".

Common Ice Nuclei include the following:

- Silver Iodide used for cloud seeding: -4 C
- Volcanic Ash: -13C
- Kaolinite (clay family): -9C
- Vermiculite (most prevalent clay): -15C

Work done by various cloud physicists suggests that about 80-90% of all ice nuclei over the upper Midwest consist of some type of clay material with *vermiculite* leading the charge.

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Cloud Droplets and Ice Nucleation

Heterogeneous Nucleation

- When "particles" introduced into the atmosphere initiate ice crystal formation… like vermiculite.

Three Possible Processes of Heterogeneous Nucleation

- Growth by diffusion deposition (depositing upon)
- Growth by contact
- Growth by freezing (ice nuclei initiate spontaneous process)

Turns out that the most common growth process is:

Growth by diffusion deposition

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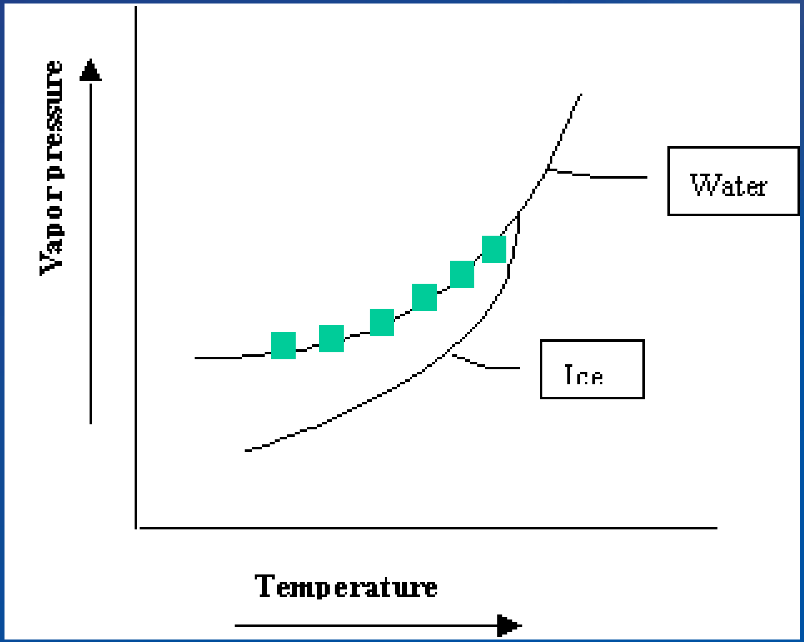
The Bergeron-Findeisen Process

- It has been experimentally verified that the saturation vapor pressure over ice is less than the saturation vapor pressure over water at the same temperature.
- This saturation vapor pressure deficit (about 0.25 mb at -12.5 C) means that when ice crystals and cloud droplets exist in the same cloud, the ice tends to grow at the expense of the cloud droplets.



Super-cooled water droplets are pulled towards the ice crystals !!

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The Bergeron-Findeisen Process

- Ice growth rate also depends on atmospheric pressure with the growth rate greater at lower pressure !

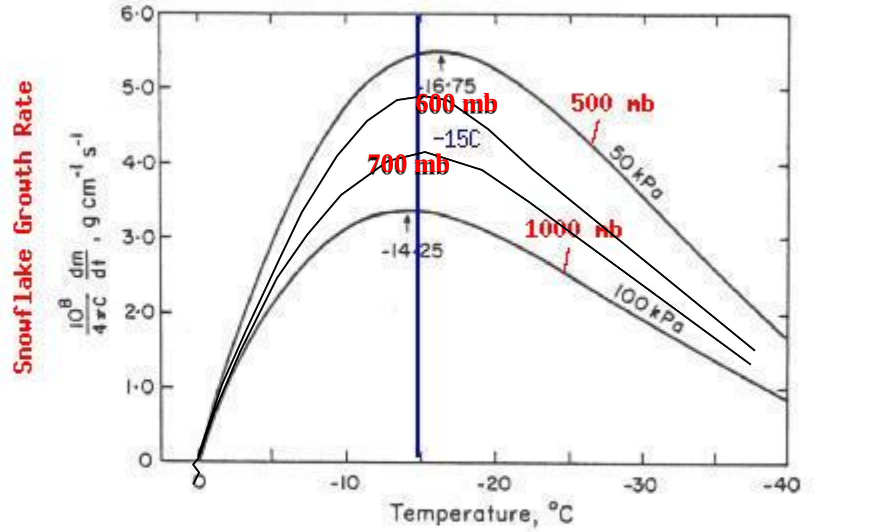

FIG. 9.4. Normalized ice crystal growth rate as a function of temperature. (Adapted from Byers, 1965.)

Growth rate is maximized around -15 C

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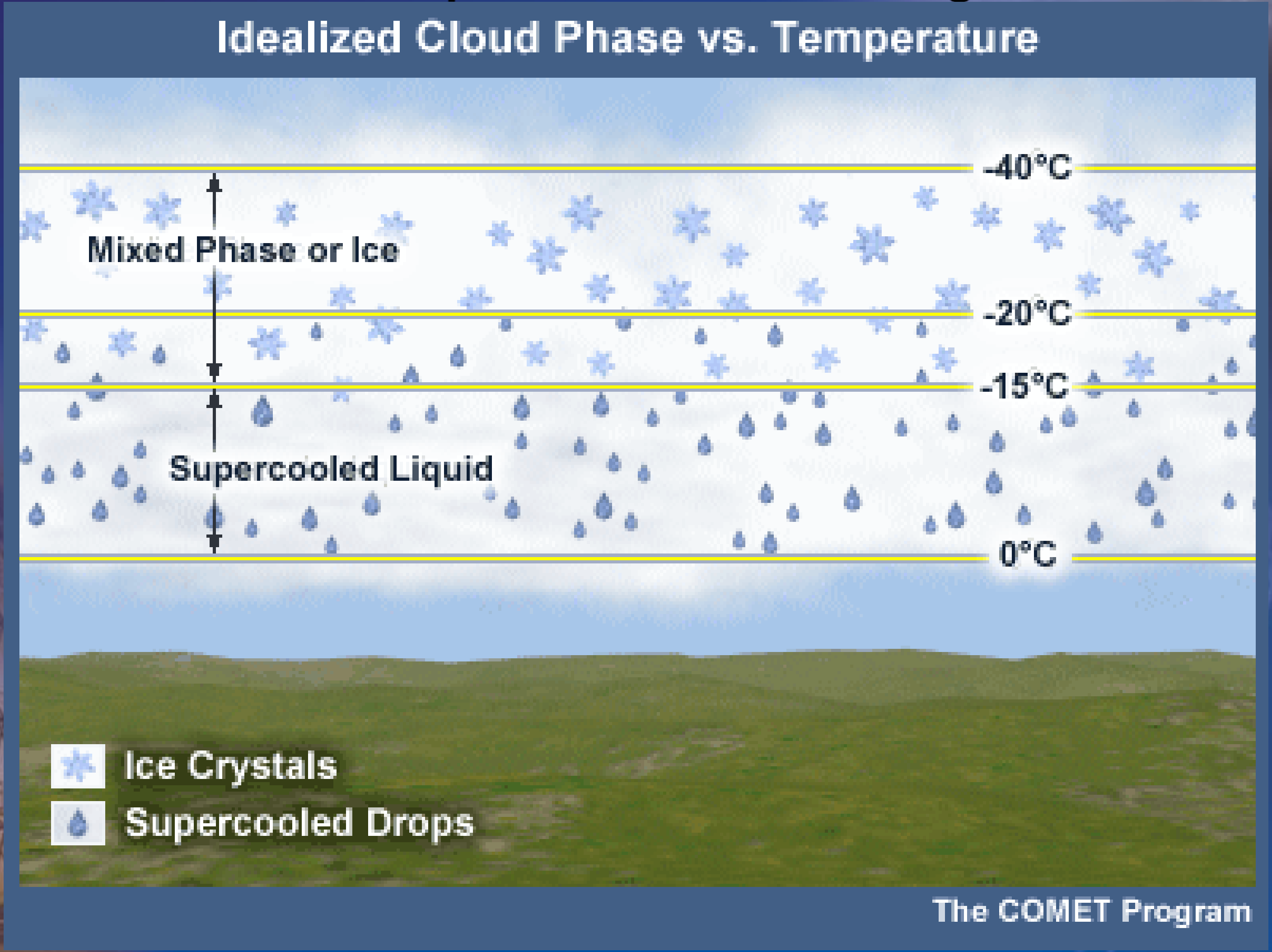
What Temperature is Cold Enough ?



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Which Snowflake is Favored at -15 C ?

The Dendrite !

The Holy Grail of snowflakes … 2-5 mm in diameter and contains plenty of "air space" in and around the flake.

High Snow:Water Ratio!

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Other Snow Growth Mechanisms

Growth by accretion… within entire cloud

- Fast falling ice crystals collect super-cooled water vapor as they fall and get larger with time. Graupel, needles, and finely dendritic flakes can grow by accretion.

Growth by aggregation… nearer cloud base

- Multiple ice crystals come together to form one main flake.
- Happens most often when cloud temperatures are warmer than -10 C (14 F).
- The largest flakes occur when the temperature of the cloud and near surface temperature is near 0 C (32 F) and the air is saturated down to the surface.

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Size of Flake by Temperature

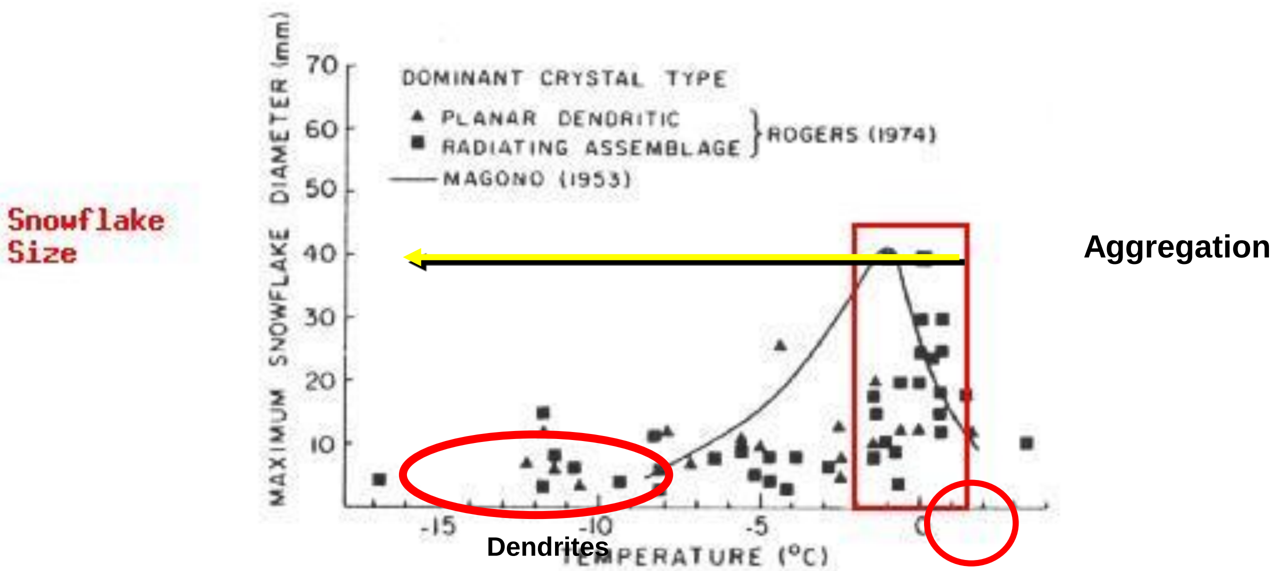

Fig. 14-19. Maximum observed snowflake diameters as a function of air temperature for two types of snowflake composition. (From Rogers, 1974b; by courtesy of the author.)

- Snowflakes can approach sizes of 40 mm … nearly 10 times the size of a fat dendrite flake !!

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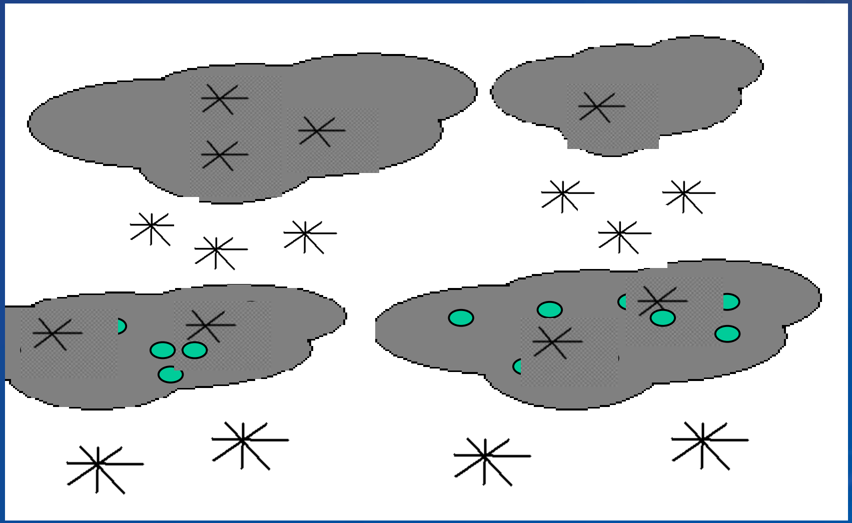
Two Snow Nucleation Processes

Seeder Feeder Mechanism – cirrus over stratus

- **Pruppacher and Klett proposed a mechanism where an upper layer clouds "seeds" a lower super-saturated cloud deck with ice crystals – causing the feeder cloud to produce precipitation.**

Seeder Clouds

Feeder Clouds



5000 feet max

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Two Snow Nucleation Processes

Rime Splintering – nearer cloud base

- **Accretive snow crystals shatter or splinter as they fall. This produces additional ice nuclei for the cloud to develop more snow flakes**
- **Normally occurs as temperatures approach -5 C when flakes have grown in size significantly.**

Rime splintering will enhance snowfall efficiency as it adds more nuclei to the cloud…however at the same time snowfall amounts may diminish due to the riming process which removes “super-cooled water vapor” from the cloud.

What About Atmospheric Lift ?

- Maximizing snowfall efficiency involves three things:

1. Snow production in the "dendritic layer" from -12 C to -18 C centered around – 15 C.
2. Sufficient moisture within the layer with relative humidity greater than 90%
3. Sufficient and sustained lift within the column cutting through the dendritic layer.

One easy way to view these processes is though BUFKIT which is available at the following address:

http://www.wbuf.noaa.gov/bufkit/bufkit.html

or simply search "BUFKIT" on Yahoo! Or Google.

BUFKIT is a program which displays atmospheric soundings … and time cross sections of moisture, temperature, and lift.

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Des Moines BUFKIT Data Page

Bufkit Data Available from NWS Des Moines - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

http://www.crh.noaa.gov/dmx/?n=bufkit

Iowa Environmental ... NCDC Home Page Storm Prediction Cent... DMX Intranet DMX SchoolNet8 | Web Ca...

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NOAA's National Weather Service Weather Forecast Office

Des Moines, IA

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City, St Go

Current Hazards
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- eSpotter
- National Drought Info.

Current Conditions
- Observations
- Satellite Images
- Rivers & Lakes AHPS
- Precip Estimate
- Snow Cover
- Weather Summary
- Local Weather Map
- More Maps
- Pollen Count

Radar Imagery
- Local Radar
- Nationwide
- Regional
- Local Radar (Dial-up)

Forecasts
- Local Area
- Aviation
- Fire Weather
- Graphical
- Interactive
- Wx Activity Planner

Bufkit Data Produced by NWS Des Moines

A limited dataset of Bufkit data is available from NWS WFO Des Moines. The sites are primarily in Iowa, however there is also some data for sites near Iowa. Bufkit is a model sounding diagnostic/prognostic tool that can be found here. The easiest method to download data is to use BufGet.tcl, an included Tcl/Tk module in the distribution found at the above website. Documentation on Bufkit and BufGet is included in the distribution. ***This data is not operational and may not always be available.***

To download the data without using BufGet, *right click* on one of the links below and, depending upon the browser you use, either select *Save Link As* or *Save Target As*. Then save to an appropriate directory and load the sounding in Bufkit.

Eta Model (00Z and 12Z model runs)
Usually available two hours after the model runtime.

Albia, IA	Cherokee, IA	Carroll, IA	Waterloo, IA	Davenport, IA	Burlington, IA
Dubuque, IA	Cedar Rapids, IA	Des Moines, IA	Fairmont, MN	Sioux Falls, SD	Omaha, NE
La Crosse, WI	Mason City, IA	Ottumwa, IA	Rockford, IL	Rochester, MN	St. Joe, MO
Sioux City, IA	Topeka, KS	Redding, IA			

Eta Model - (06Z and 18Z model runs)
Usually available two hours after the model runtime.

Done

start | Bufkit Data Av... | NWSFO Des M... | The Importan... | NWS La Cross... | Microsoft Pow... | Calculator | 2:34 PM

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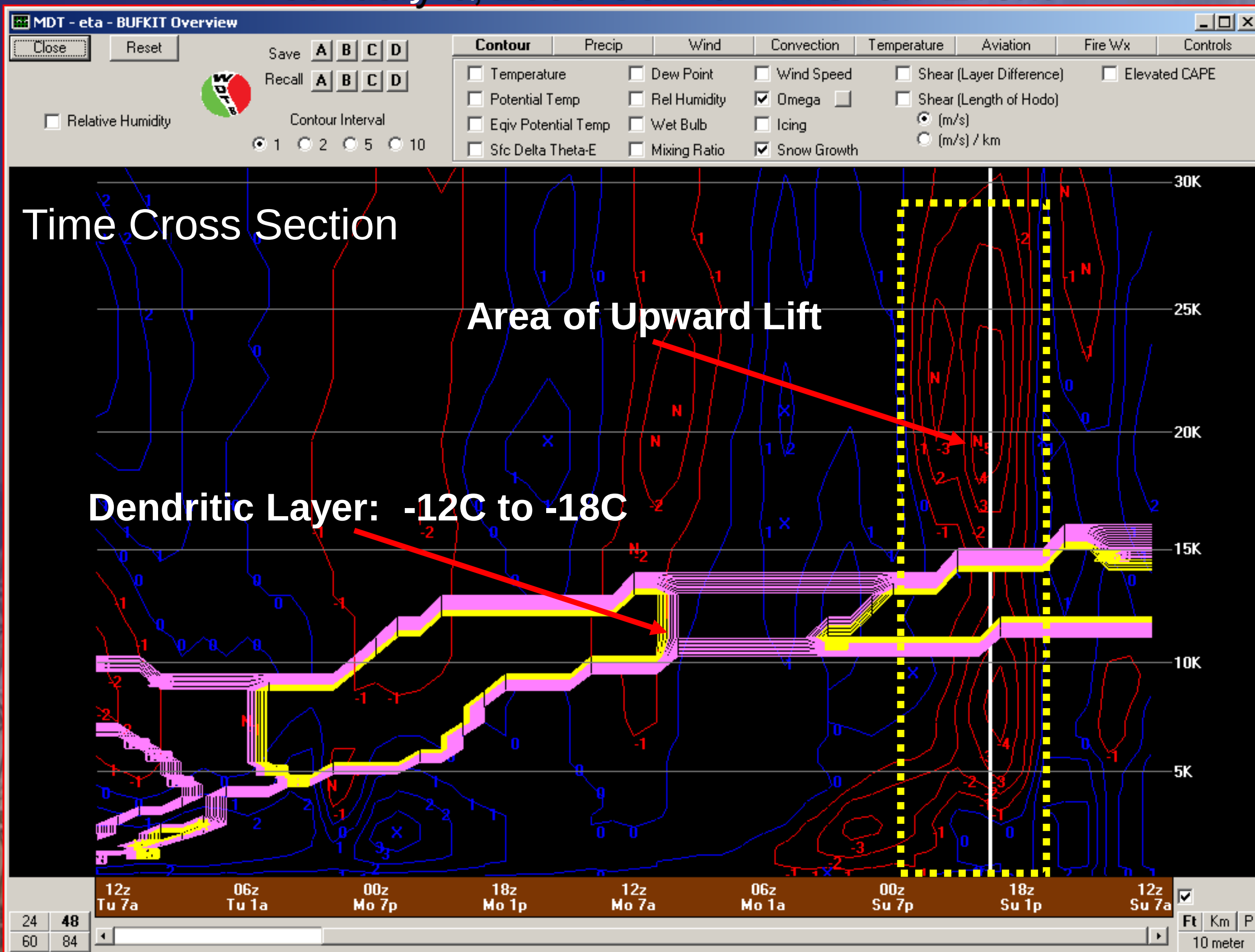
BUFKIT Applications

January 5, 2003 Central PA Snow Event



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Let's Summarize Snow Microphysics

- Vertical motion and snow microphysics greatly impacts snowfall efficiency.

- Turns out that the most common growth process is:

Growth by diffusion deposition

- -10 C 60% chance ice is in the cloud - warm cutoff
- Operationally -12 C 70% chance ICE is in the cloud

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Let's Summarize Snow Microphysics

- Dendrites are the favored type of snowflakes for high efficiency snowfall events and occur in the –12 C to -18 C "dendritic layer".
- Other snow growth processes include aggregation and accretion.
- Other ice nucleation processes include the seeder-feeder effect and rime splintering.
- BUFKIT cross sections can be utilized to locate periods of maximum snowfall efficiency at a given location – *provided the numerical forecast models accurately depict the evolution of the snow event in your area !!*

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Top-Down Approach to Precipitation Type

Previous methods focused on "thickness of layer" or "warmth of a layer" in question to decide between frozen, mixed, or liquid precipitation at a location.

Common snow benchmark values for various pressure layers:

- **1000 – 500 mb thickness: less than 5400 meters : snow**
- **1000 – 850 mb thickness: less than 1300 meters: snow**
- **1000 - 700 mb thickness: less than 2840 meters: snow**

Thickness equation:

$$-\frac{R\overline{T}}{g}\int_{pl}^{pu}\frac{1}{p}\frac{\partial p}{\partial t} = \int_{zl}^{zu}\frac{\partial z}{\partial t}$$

$-\,or\,-$

$$\Delta z = zu - zl = -\frac{R\overline{T}}{g}\ln\left(\frac{pu}{pl}\right)$$

Average Temperature

Related to thickness

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Top-Down Approach to Precipitation Type

Today's preferred method examines the temperature profile of the atmosphere at the location(s) of expected precipitation …

Three Considerations for the Top-Down Approach:

- **Does the cloud column have ice nuclei available for the production of frozen precipitation ?**
- **Are there any warm or dry layers above the surface layer ?**
- **What is the temperature and moisture content of the surface layer ?**

There may be a need to consider the T_w temperature at the surface!

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Top-Down Approach to Precipitation Type

Layer	Air Mass	Hydrometeor Impact
Ice Producing Layer	Cold, midlevel air mass	Ice crystal nucleation and growth
Warm Layer	Elevated, warm tropical air mass	Warming, melting
Cold Surface Layer	Surface Arctic or modified air mass	Refreezing/contact freezing

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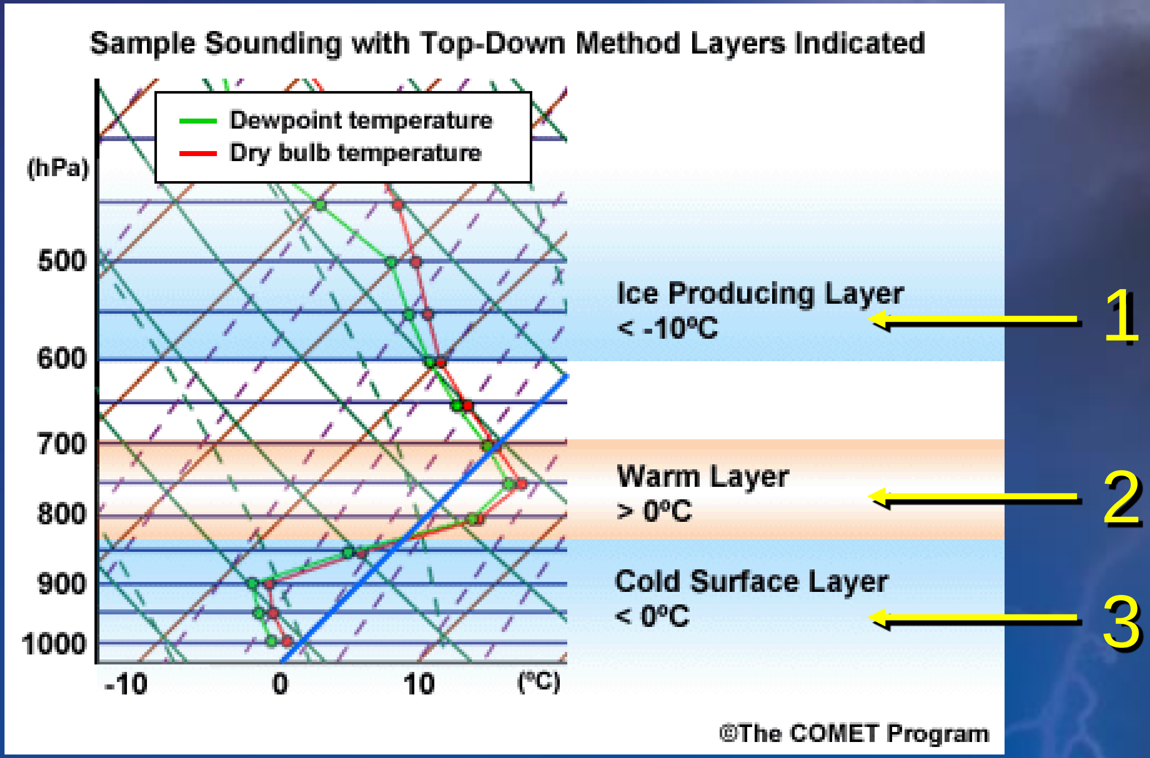
Top-Down Approach to Precipitation Type



Here is our sample "winter" sounding with the three layers of consideration in the Top-Down method !

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Top-Down Approach to Precipitation Type

Elevated Warm Layer

Let's also assume that the surface layer is colder than 0 C.

Warm Layer Max Temp ^{0}C	Precipitation Type with ice introduced	Precipitation Type without ice introduced
< 1^{0}C	snow	freezing rain or drizzle
1 to 3^{0}C	snow/ice pellet mix (1^{0}C) to ice pellets (3^{0}C)	freezing rain or drizzle
> 3^{0}C	freezing rain or drizzle	freezing rain or drizzle

Assessing a cold and dry surface layer for precipitation type is much more difficult … see the flow chart handout for details.

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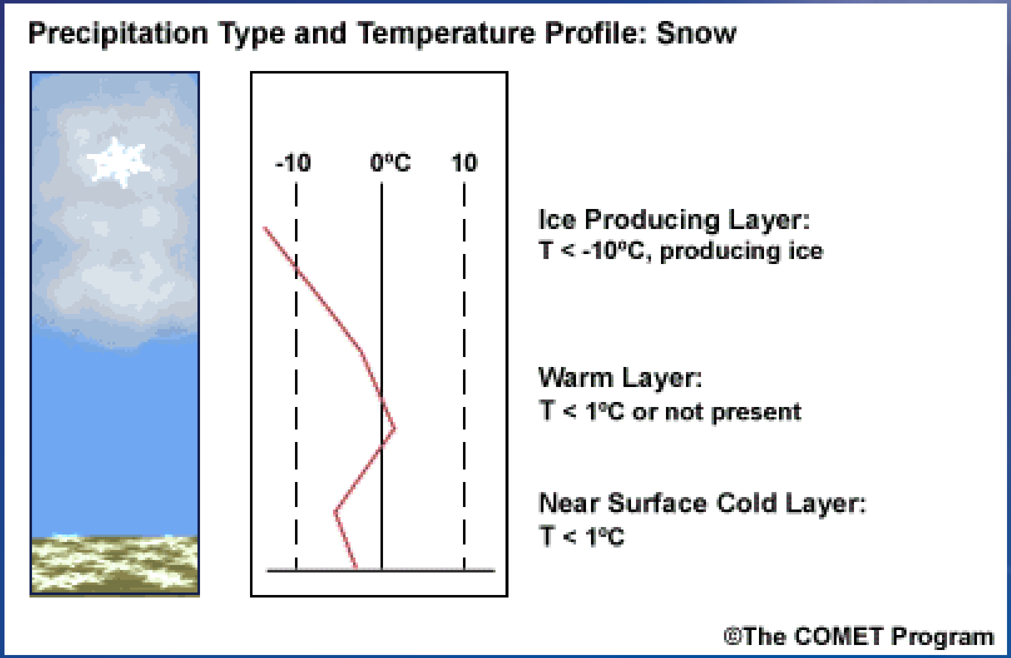
Top-Down Approach to Precipitation Type



A typical snow profile ….

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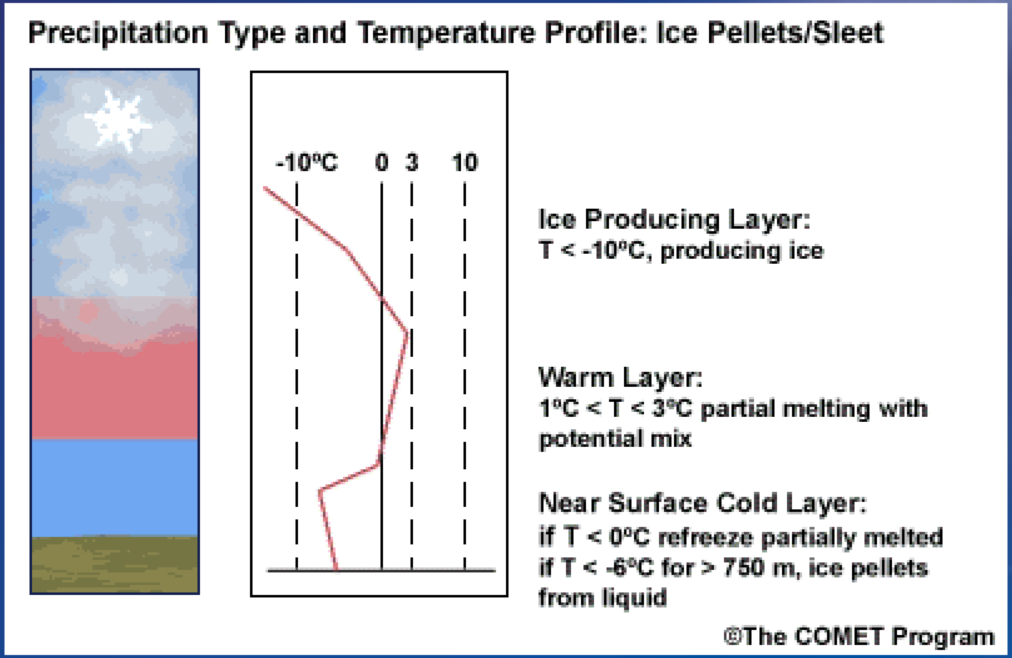
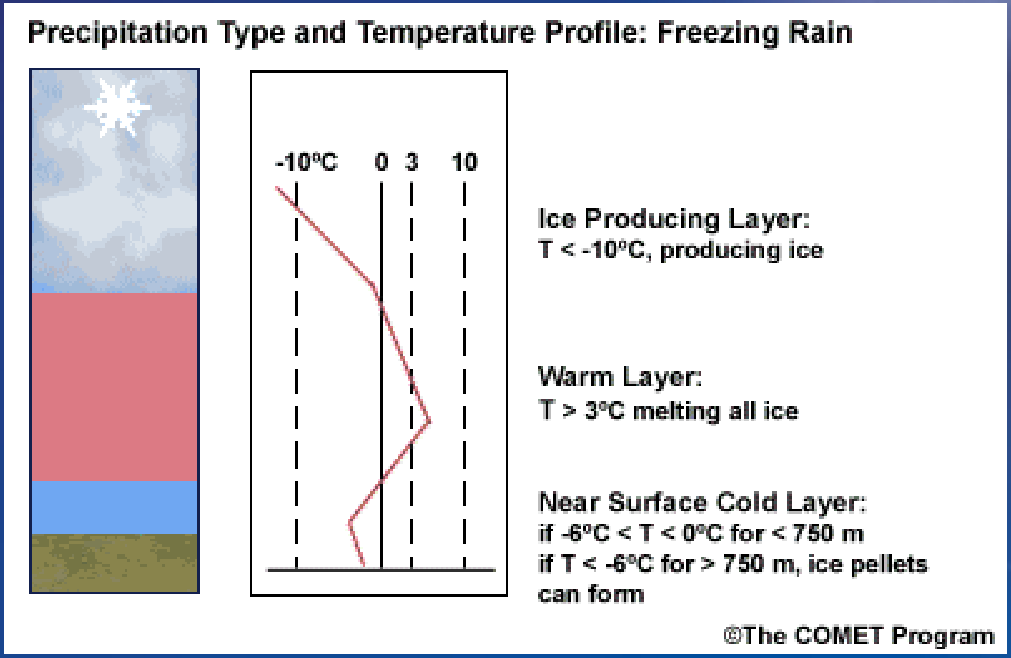
Top-Down Approach to Precipitation Type



A typical mixed precipitation profile ….

Top-Down Approach to Precipitation Type



A typical freezing rain profile ….

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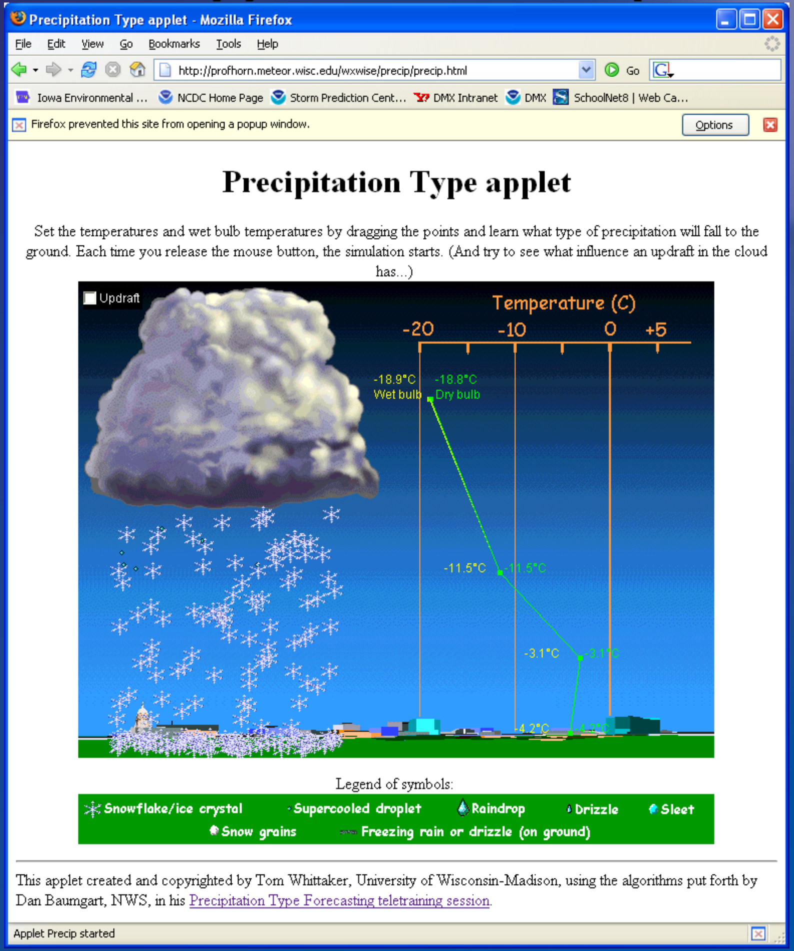
Top-Down Approach to Precipitation Type



Interactive Java Applet which allows you to create a "profile" and see how changes in conditions affect precipitation type using the Top-Down approach !! …http://profhorn.meteor.wisc.edu/wxwise/precip/precip.html

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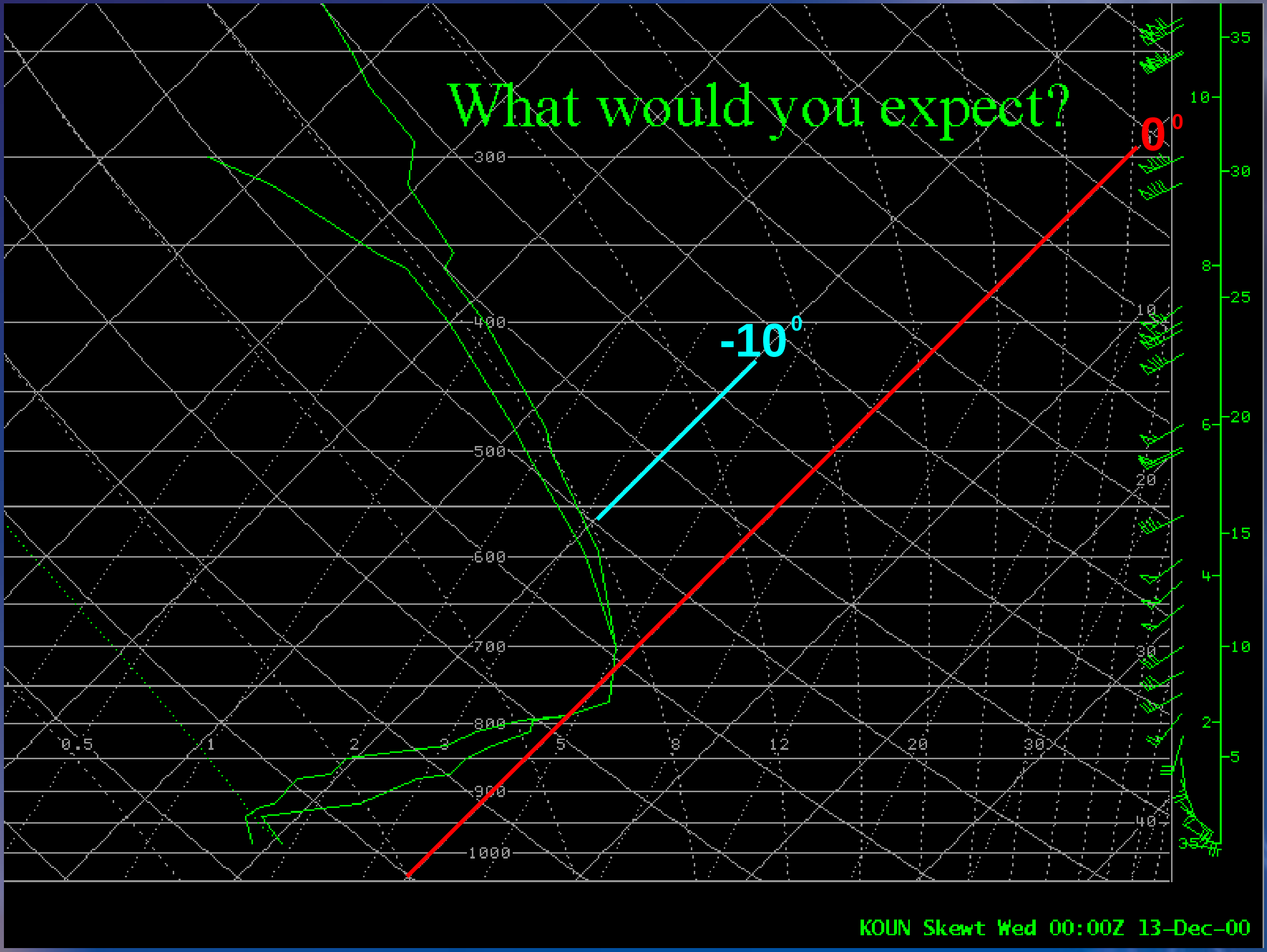
Let's Try a Few Examples !!



We have ice at -10 °C … we have a weak elevated warm layer. We also have a rather dry surface layer … mainly sleet fell here !

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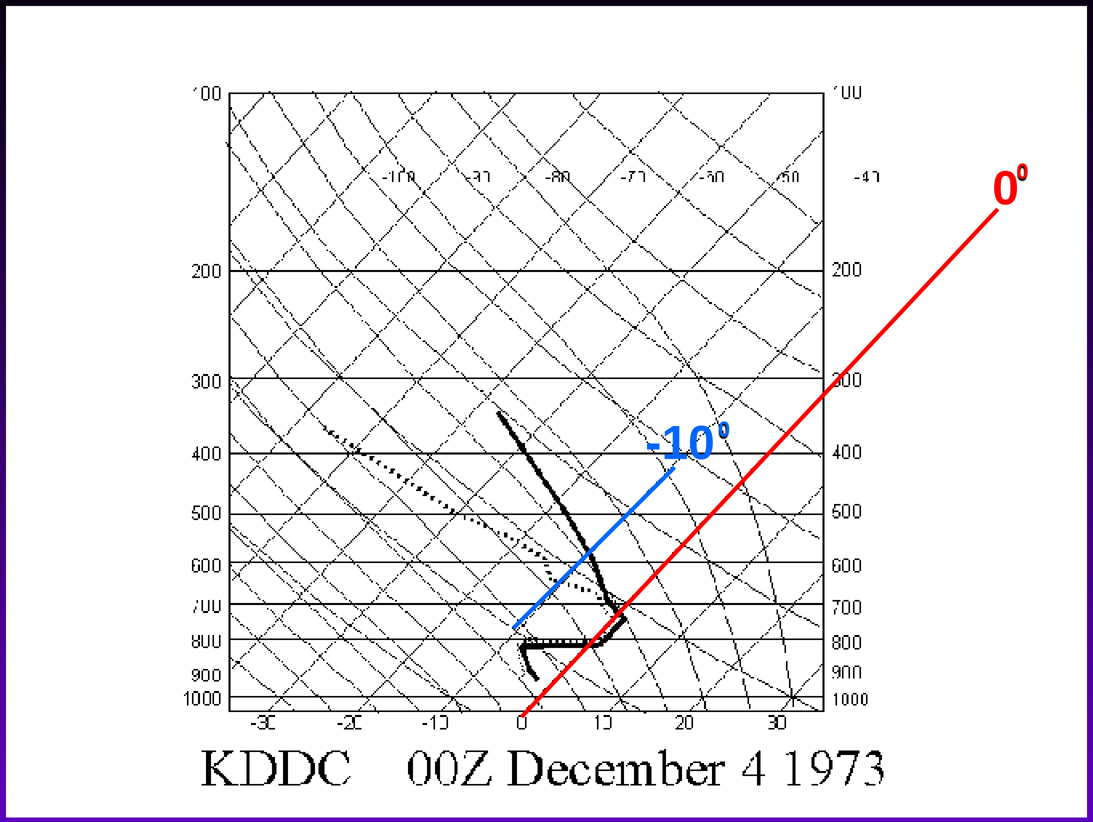
Let’s Try a Few Examples !!

What would you expect?



We have no ice at -10^0 C … we have an elevated warm layer. We also have a cold surface layer which is below 0^0 C … freezing drizzle fell here !

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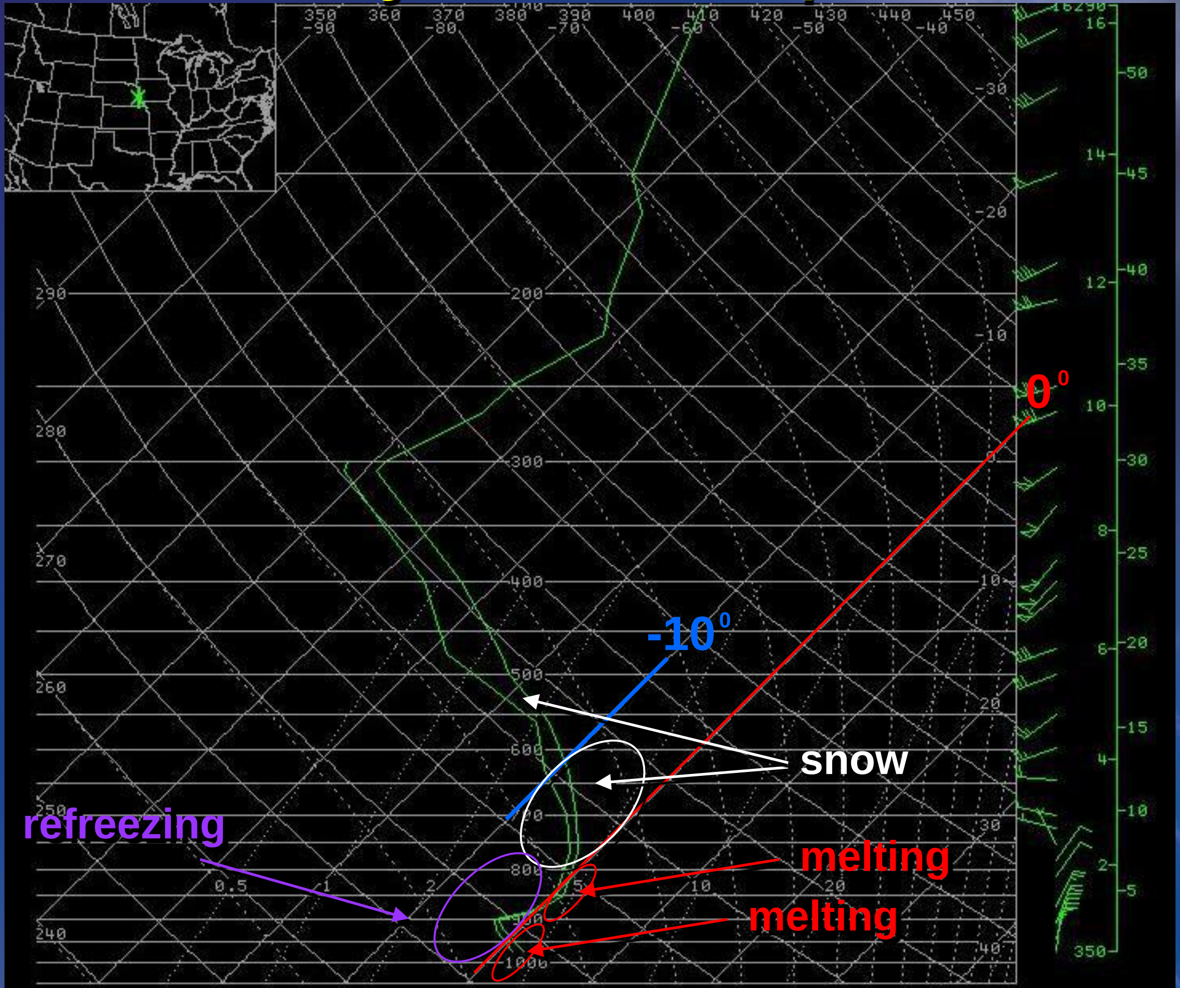
Let's Try a Few Examples !!

Omaha, NE

Oct 21, 2006

At 7 am



We have ice at -10⁰C and colder … we have a very small elevated warm layer. We also have a warm surface layer which is above 0⁰ C just above ground… rain and light snow fell here !

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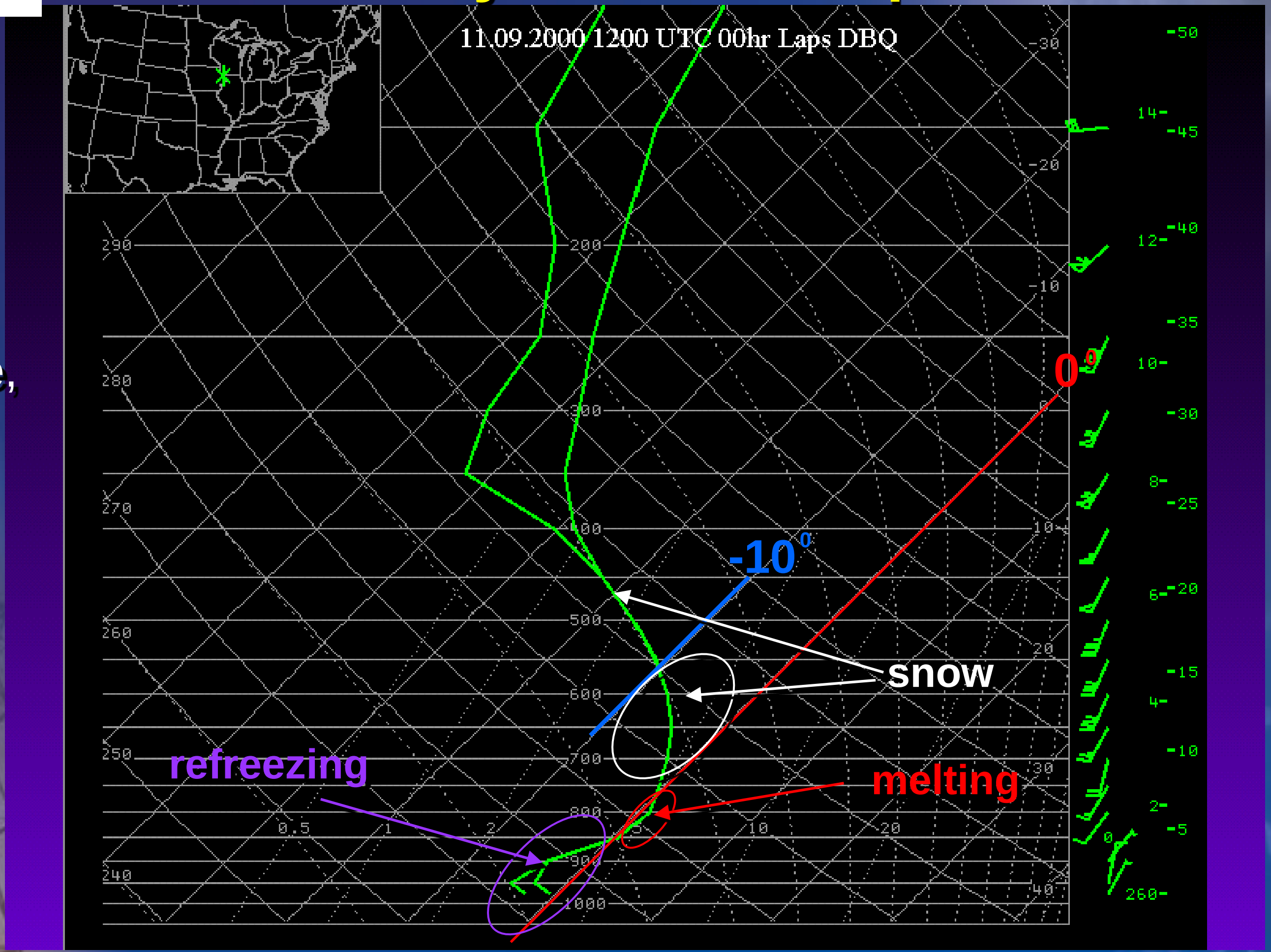
Let's Try a Few Examples !!

Dubuque, IA

Nov 09, 2000

At 7 am



We have ice at -10 °C … we have a 50 mb elevated +0.5 °C layer. We are cold at the surface which some dry air at the surface … mainly snow and some sleet fell here !

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A Brief Guideline for Snowfall Ratios

Common Snowfall Aggregates and Snow Ratios

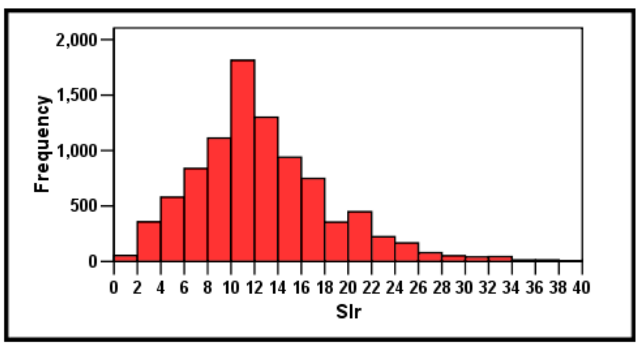
Snow Aggregate	Snow|Water Ratio
Dendrite aggregate Stellar dendrites > 25:1 Needle assemblages	> 16 to 1
Mixed crystals Plates, columns, needles, and spatial dendrites Lightly rimed stellar crystals or needle assemblages	9 – 16 to 1
Moderate to heavily rimed crystals and/or partially melted	3 – 8 to 1
Ice pellets and graupel	2 – 5 to 1

Snow Microphysics and the Top-Down Approach to Forecasting Winter Weather Precipitation Type

A Brief Guideline for Snowfall Ratios

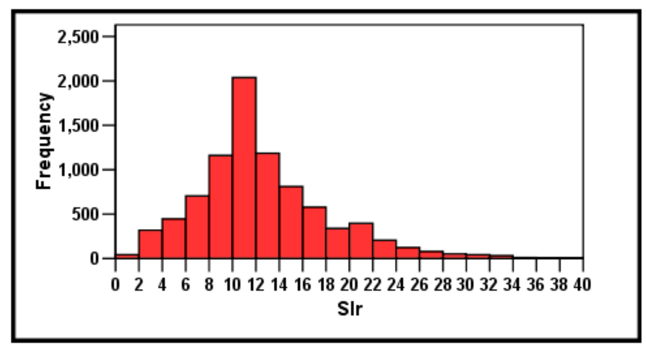
Omaha/Valley, NE

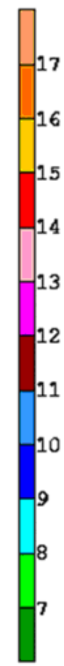
Avg SLR: 12.7
Standard Dev: 6.2
75th Percentile: 15.8
50th Percentile: 11.7
25th Percentile: 8.9



Des Moines, IA

Avg SLR: 12.6
Standard Dev: 6.2
75th Percentile: 15.2
50th Percentile: 11.4
25th Percentile: 9.1





Marty Baxter – St. Louis University

Snow Microphysics and the Top-Down Approach to Forecasting Winter Weather Precipitation Type

Let's Summarize The Top-Down Approach

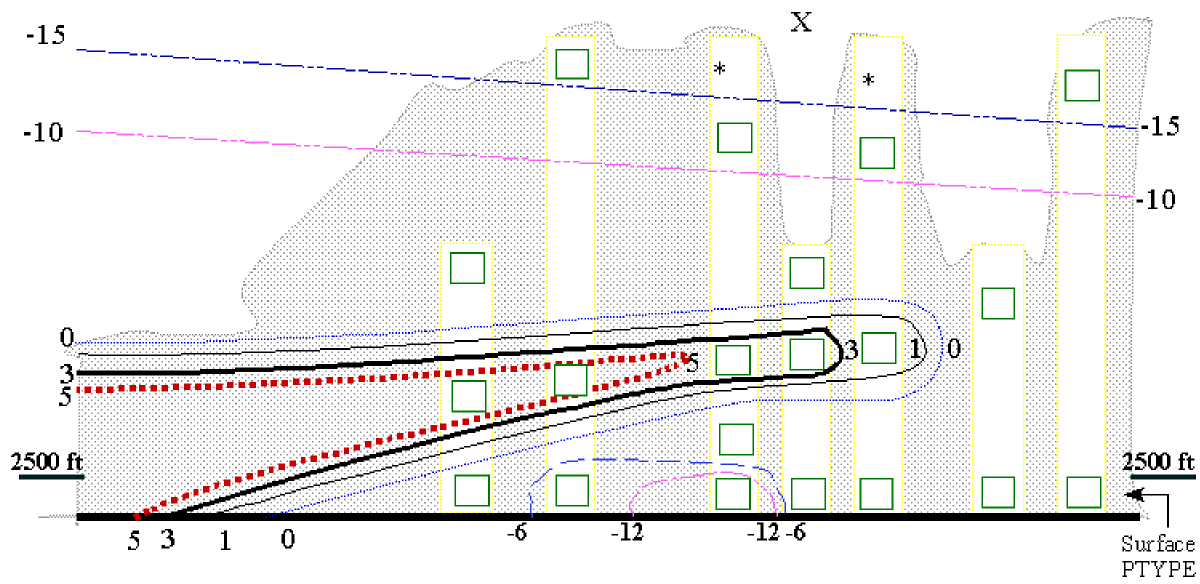
- Consider the ice production layer; any elevated warm layers; and the surface layer when deciding on type.
- Examine warm layers for degree of temperature rise; examine cold layers for temperature and degree of dryness (T_w) which may lead to cooling with evaporation.
- Consider elevated precipitation processes such as the seeder-feeder effect and possible convection … both which may seed a lower cloud with ice nuclei.
- Utilize forecast soundings (BUFKIT) once again to examine the layers during an event not only changes in precipitation type over a forecast area … but also for changes in precipitation type over time !!

No Questions ?? OK

Final Exam !!

Exercise: Work through each vertical column using the Top-Down Approach techniques from the training. The lowest box in each column represents your surface observed precipitation type. In each box, fill in the expected hydrometeor "state". The shaded area represents saturated cloud '*' represents ice crystals, and all temperatures are in degrees C. The following are the possible hydrometeor "states" and their abbreviations.

SN or * = Snow/Ice — L = Liquid
PL = Sleet — S = Supercooled Liquid
FZ = Freezing Precipitation



Version 12/2001

Answer at: http://www.crh.noaa.gov/arx/micro/ptypea.gif

Thanks for attending !!