

# A Winter Forecasting Handbook



## Winter storm information that is useful to the public:

- 1) The time of onset of dangerous winter weather conditions
- 2) The time that dangerous winter weather conditions will abate
- 3) The type of winter weather to be expected:
  - a) Snow
  - b) Sleet
  - c) Freezing rain
  - d) Transitions between these three
- 7) The intensity of the precipitation
- 8) The total amount of precipitation that will accumulate
- 9) The temperatures during the storm (particularly if they are dangerously low)
- 7) The winds and wind chill temperature (particularly if winds cause blizzard conditions where visibility is reduced).
- 8) The uncertainty in the forecast.

## **Some problems facing meteorologists:**

Winter precipitation occurs on the mesoscale

The type and intensity of winter precipitation varies over short distances.

Forecast products are not well tailored to winter

Subtle features, such as variations in the wet bulb temperature, orography, urban heat islands, warm layers aloft, dry layers, small variations in cyclone track, surface temperature, and others all can influence the severity and character of a winter storm event.

# FORECASTING WINTER WEATHER

Important factors:

1. Forcing
  - a) Frontal forcing (at surface and aloft)
  - b) Jetstream forcing
  - c) Location where forcing will occur
2. Quantitative precipitation forecasts from models
3. Thermal structure where forcing and precipitation are expected
4. Moisture distribution in region where forcing and precipitation are expected.
5. Consideration of microphysical processes

Forecasting winter precipitation in 0-48 hour time range:

You must have a good understanding of the current state of the Atmosphere BEFORE you try to forecast a future state!

1. Examine current data to identify positions of cyclones and anticyclones and the location and types of fronts.
  - a. Begin by roughly analyzing the surface chart for frontal boundaries
  - b. Examine a loop of water vapor and IR satellite imagery to locate boundaries aloft (dry slots, moisture bands, clouds, dry filaments)
  - c. Examine radar imagery to determine where precipitation features exist and how they are organized.
  - d. examine constant pressure charts to identify any boundaries present on the satellite images
  - e. examine key isentropic levels to determine where regions of ascent and descent are occurring
  - f. Create a few key cross sections ( $\theta$ ,  $\theta_e$ , RH, wind, ageostrophic circulation vectors) to confirm that fronts and other minor boundaries exist where you suspect they exist.

## 2. Examine the jetstream

- a) Which jetstreams are likely to be important in the evolution of upcoming winter events?
- b) Are jetstreaks present? What is their position relative to the troughs and ridges in the flow?
- c) What is their intensity?
- d) If there are multiple jetstreams, are they positioned so that there is the possibility of jetstreak interactions?

## 3. Examine the absolute vorticity distribution at 500 mb

- a) Where are the short waves in the flow?
- b) Are these waves tied to any incipient cyclones.

## 4. Examine the moisture distribution

- a) What are the potential moisture sources for a developing event?
- b) Does sufficient moisture currently exist in the vicinity of the forcing (fronts, jetstreaks)?
- c) Are there any low level dry airmasses that could inhibit precipitation or upper level dry airmasses that could prematurely end a precipitation event?

## 5. Examine the thermal structure

- a) What is the current position of the freezing line?
- b) What is the shape of the 0°C isotherm and the wet bulb temperature in cross sections – is a warm layer present aloft that could permit freezing rain to occur?
- c) What is the width and orientation of the potential zone of freezing rain?
- d) What is the stability in the vicinity of precipitation?

Once you believe you have a good understanding of the current weather situation, begin the forecast procedure

1. Following the forecast funnel, start with the large scale guidance over the continental scale to identify potential forecast problems. Compare WRF and GFS initialization and predictions.
  - a) Do this by identifying weather features that can produce significant winter weather phenomena.
    - At upper levels (200-300 hPa), are there jet streaks or large scale troughs predicted?
    - At mid-levels (500 hPa), is there a short wave trough and associated PVA coming over the region?
    - At the low levels (surface and 850 hPa), will cyclones form or pass over the area, will fronts cross the region, or is there a cold air outbreak predicted?

## Now, come down to the synoptic scale

### 1. The 300 mb progs

Examine how the jetstream and jetstreaks are evolving during the forecast period, where the forcing will be for cyclone development, and where vertical circulations associated with the jetstream may occur. Also look for diffluence/convergence patterns which help/inhibit rising motion in the mid-levels.

### 2. The 500 mb progs:

The 500 chart is the best location to associate differential PVA/NVA with rising motion in the mid-levels.

- PVA leads to rising motion, and geopotential height and surface pressure falls and convergence (helping surface cyclones intensify). It also cools and relatively moistens the atmospheric column, aiding precipitation development.
- NVA corresponds with sinking motion, pressure increases at the surface and geopotential height rises, and drying of the atmospheric column.

#### 4. The 850 mb progs:

- a. 850 mb is the best level to identify the primary thermal boundaries and the distribution of moisture. Look for evidence of tightening of the thermal gradients (frontogenesis, steepening of the frontal surface), which suggests concentrated regions of ascent.

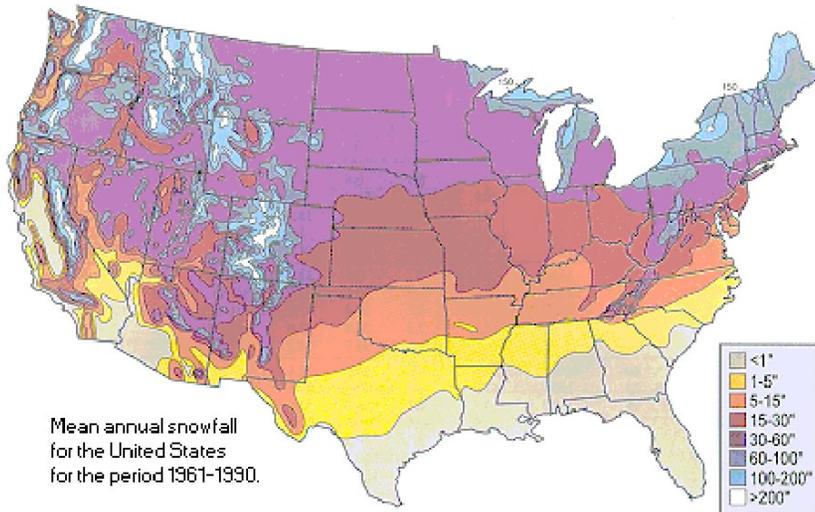
#### 3. The surface progs:

- a. Examine the 6 hourly evolution of the sea level pressure pattern, the surface temperature, and the predicted precipitation distribution. Determine where the potential for significant winter precipitation exists.
- b. Examine the evolution of the surface boundaries. Where are the surface fronts? How do they relate to the precipitation distribution?

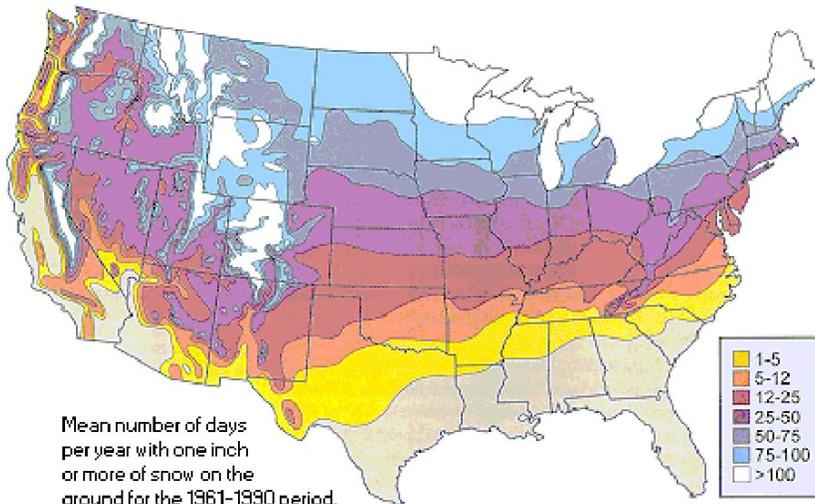
For winter forecasting, there are several phenomena of primary importance:

- 1) Heavy snowfall
- 2) Heavy rainfall -> snowmelt -> flooding
- 3) Blizzards (snow with strong winds and reduced visibility)
- 4) Freezing rain/drizzle
- 5) Dense fog (advection, radiation)
- 6) Extreme cold (wind chill)

# HEAVY SNOWFALL

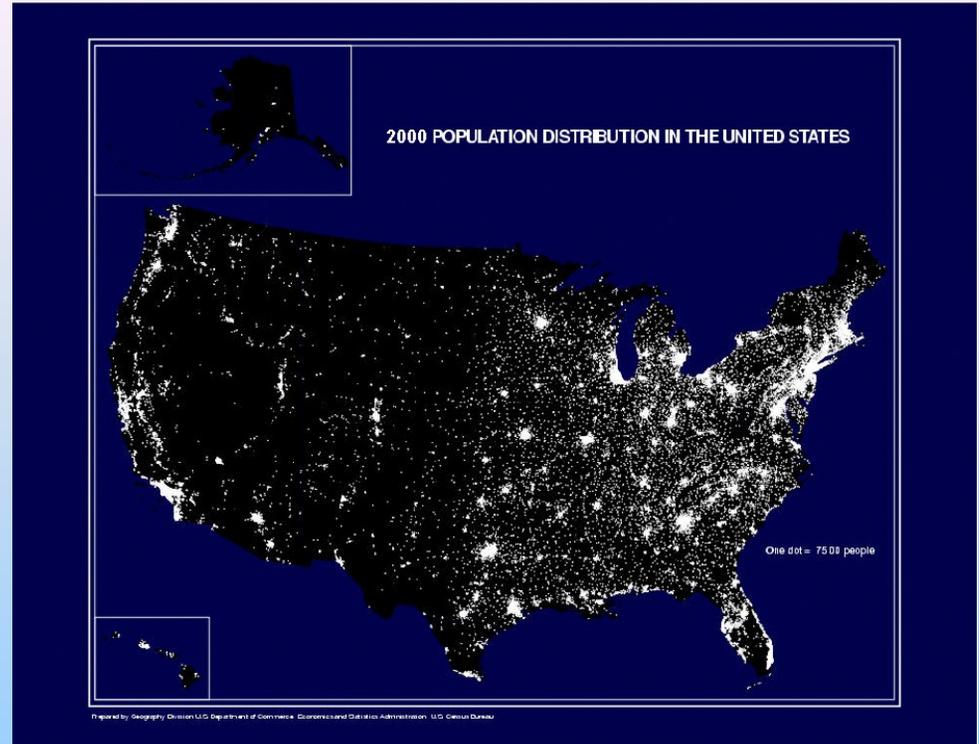


Mean annual snowfall for the United States for the period 1961-1990.



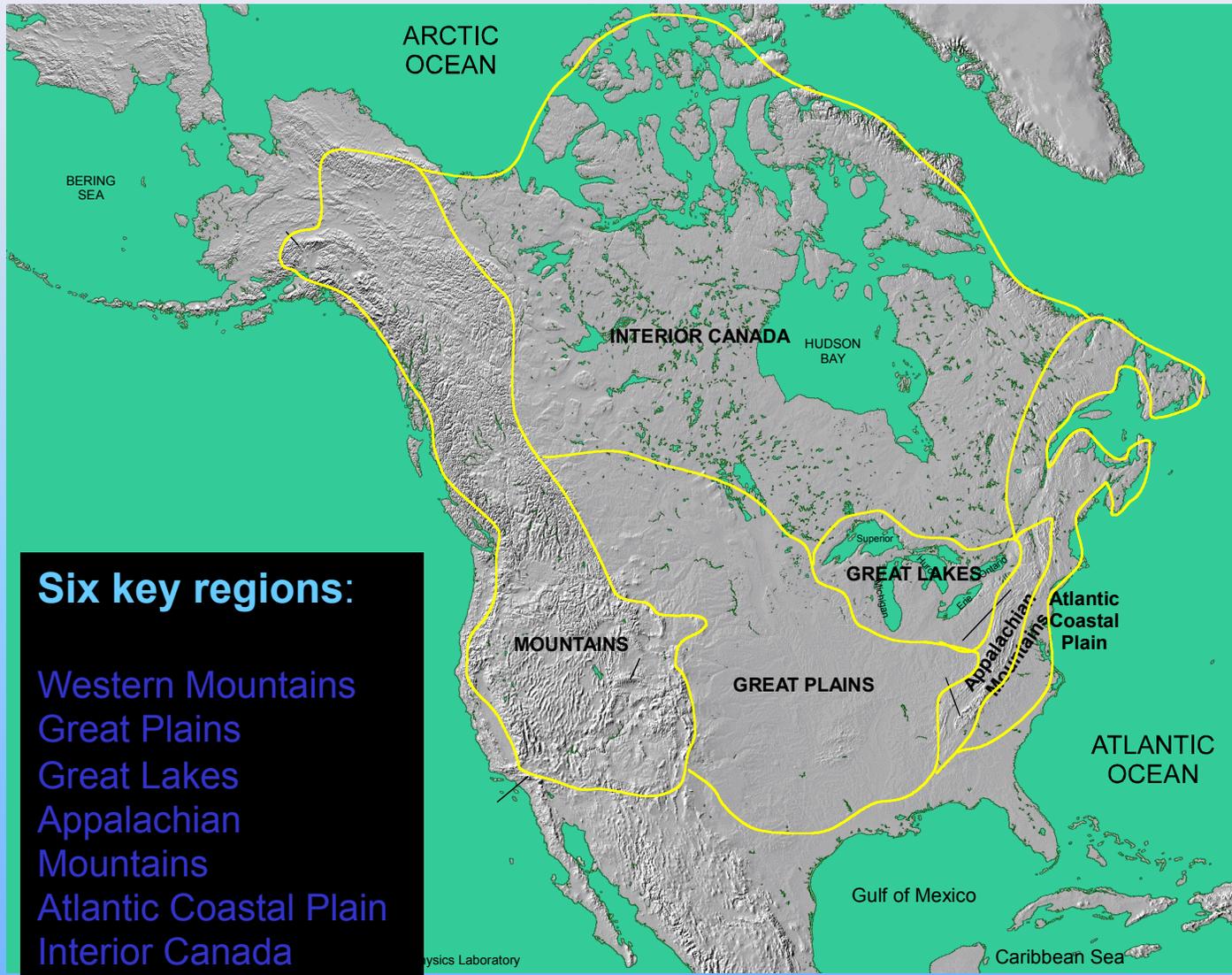
Mean number of days per year with one inch or more of snow on the ground for the 1961-1990 period.

© Colorado Climate Center, Colorado State University  
Used with permission.



The U.S. population map above and the climatology to the right clearly show where snowfall forecasts are the most critical for a large part of the population.

**Heavy snowfall:** Methods for forecasting snowfall amounts are regional – dependent on topography, elevation, and proximity to lakes and oceans



## Mountains of western U.S./Canada

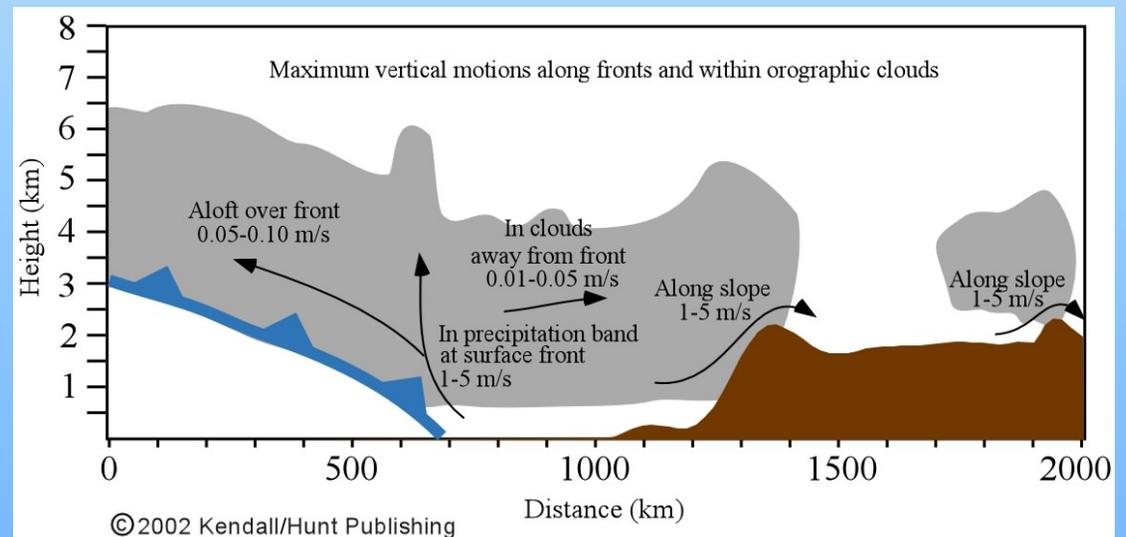
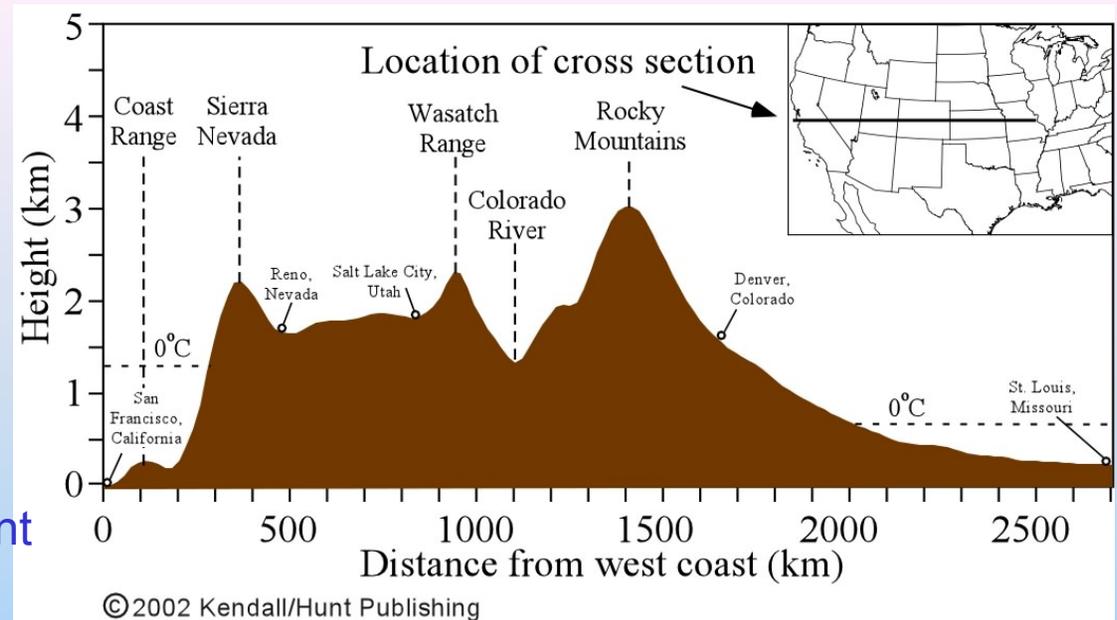
Sierra-Nevada and Cascade Range:

Key factors:

1. Height of freezing level
2. Magnitude of wind component normal to mountain range at 700 mb (~ mountaintop)
3. Length of time that moist air will be flowing toward mountain during approaching and passing cyclonic storm
4. Altitude
5. Snow/water ratio (~10:1)

Key problems:

1. Transportation across passes
2. Avalanches



## Mountains of Western U.S./Canada

Interior ranges:

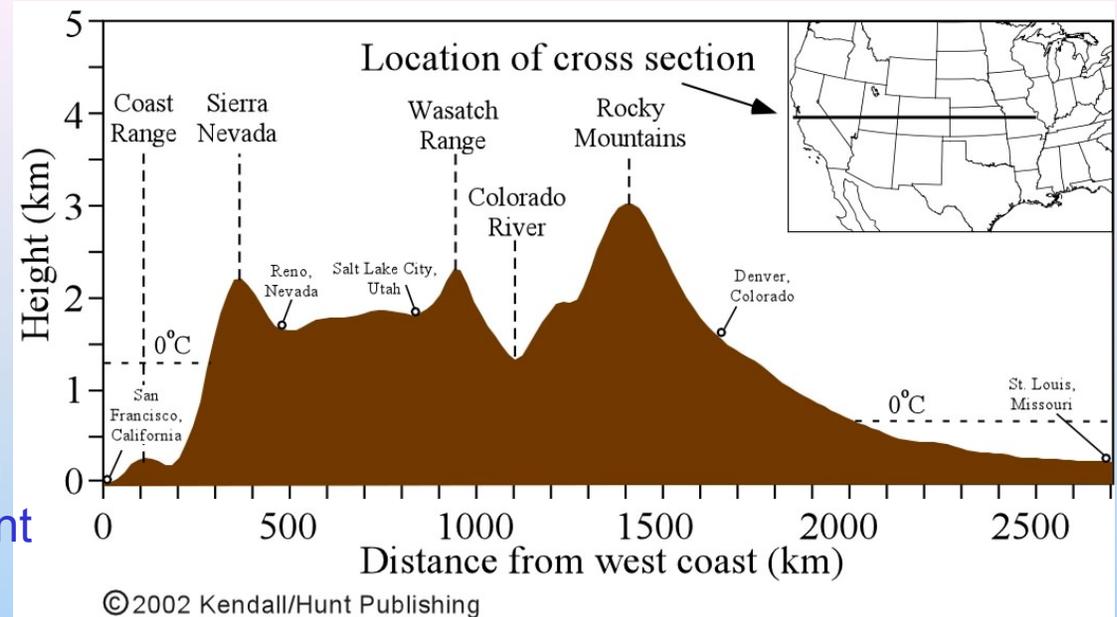
West slope of Rockies:

Key factors:

1. Height of freezing level irrelevant (all snow in winter)
2. Magnitude of wind component normal to mountain range at 700 mb (~ mountaintop)
3. Length of time that moist air will be flowing toward mountain during decaying cyclonic storms
4. Altitude
5. Snow/water ratio (~15:1 to 40:1)

Key problems:

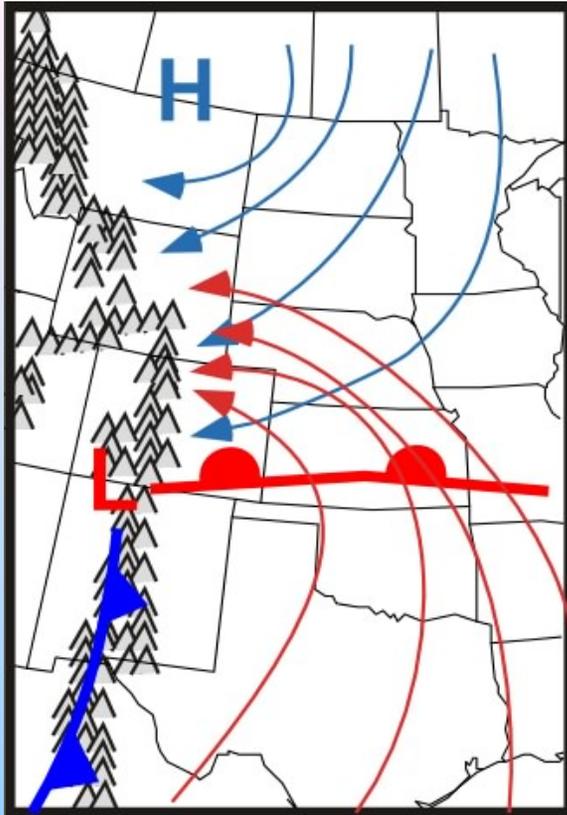
1. Transportation across passes
2. Avalanches



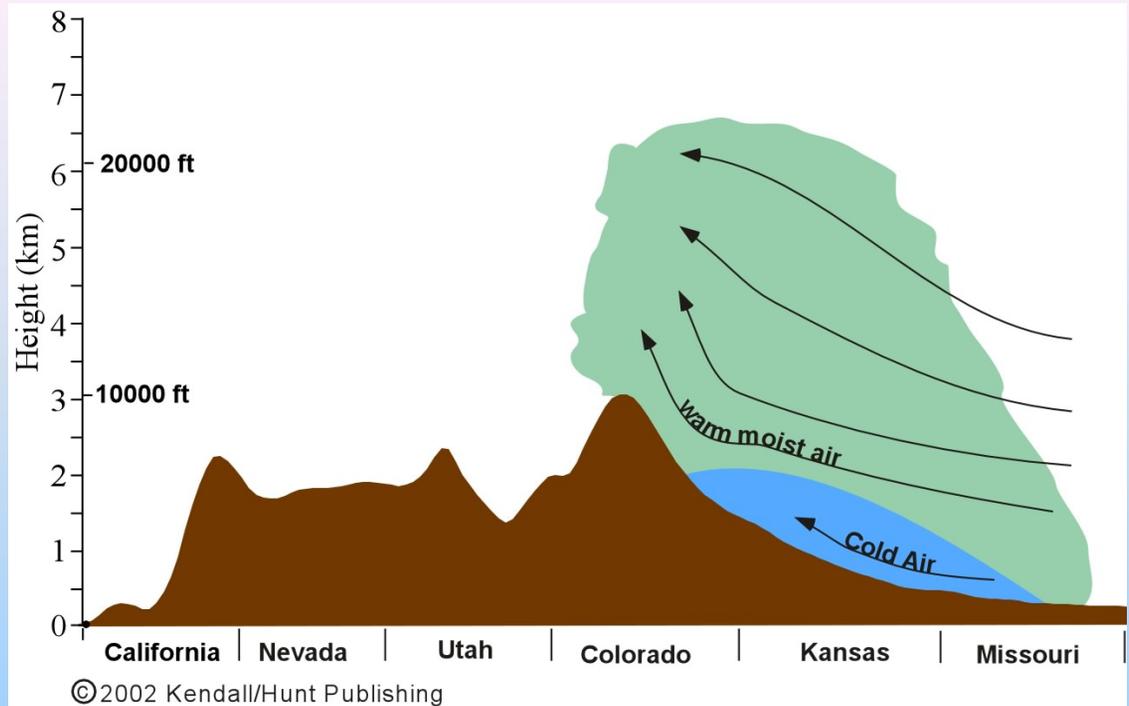
Accumulations on mountain passes range from 1-2 inches per hour on interior mountains and 2-3 inches per hour on coastal mountains.

Storms last for a day or more, and sometimes as long as a week when a series of cyclones pass and the flow is strong and westerly.

Frontal structures are difficult to identify, cyclones lose identity once they make landfall. Primary forcing is orographic lifting of moist airstream.



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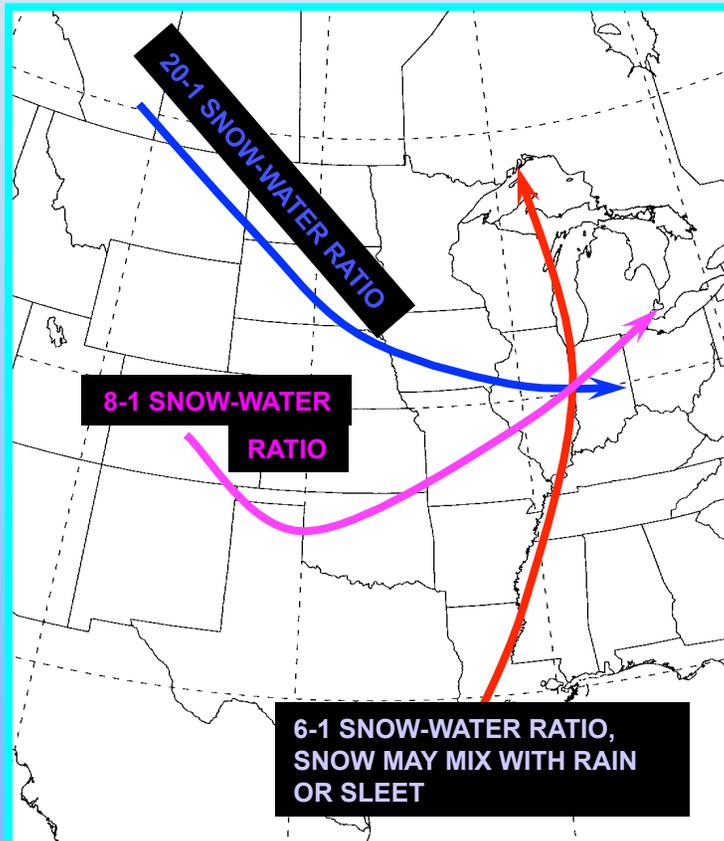
## Upslope storms along the Front Range of the Colorado Rockies

One of the primary population centers and transportation hubs of the U.S.

Gateway to western U.S. for transportation via I-70 (in Colorado) and I-80 (in Wyoming)

# Snowfall forecasting for the Great Plains

The Great Plains are affected by cyclones originating in three regions – the snow to liquid ratio varies with region, primarily because the temperature of snow formation and crystal growth differs with each storm type.



AVERAGE SNOW-WATER RATIOS FOR FOR SOUTHEASTERN WISCONSIN WITH VARIOUS STORM TRACKS

1) Northern storm tracks that favor snow crystal growth by deposition favor high snow-water ratios.

2) When ice crystals grow by riming or crystals colliding with supercooled droplets, the snow-water ratios are lower.

3) Southern storm tracks and tracks that tap moisture and warm air from oceans rarely have snow to water ratios that are greater than 10-1 except well west of the storm track. Look for low ratios where precipitation becomes mixed with sleet.

Adapted from Harms, 1970

Heavy Snowfall typically occurs north of the cyclone track

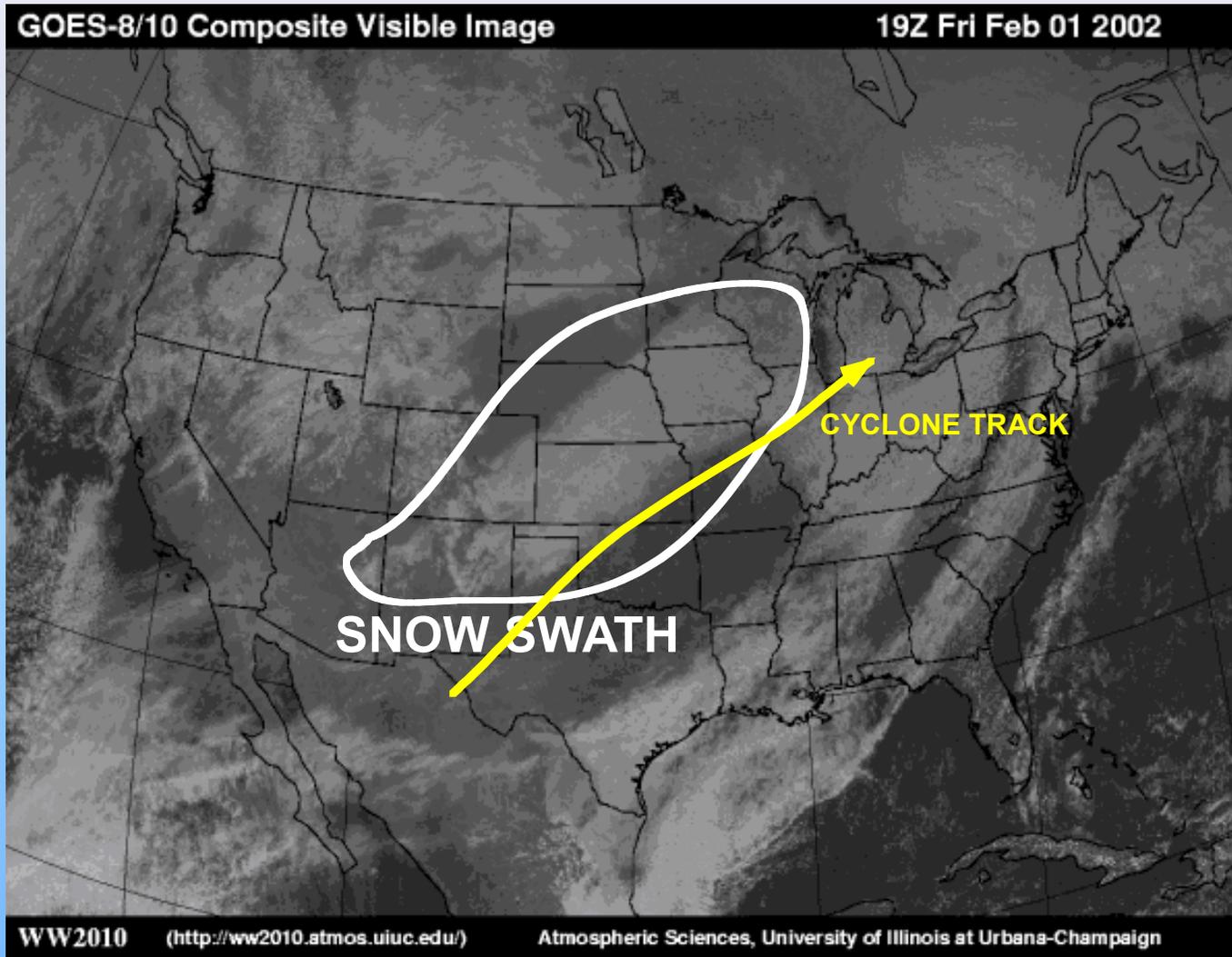
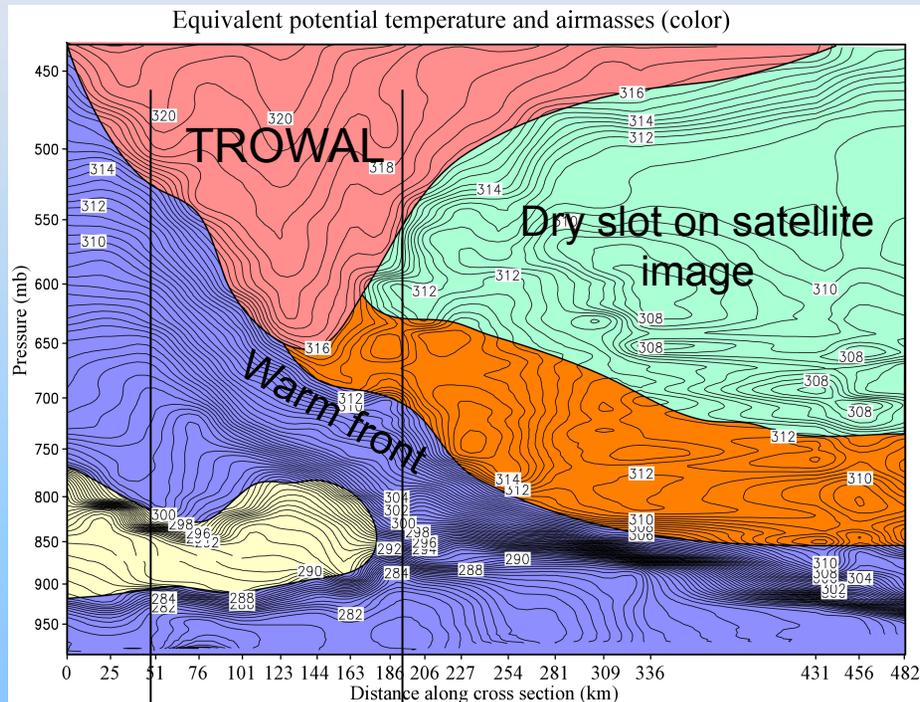
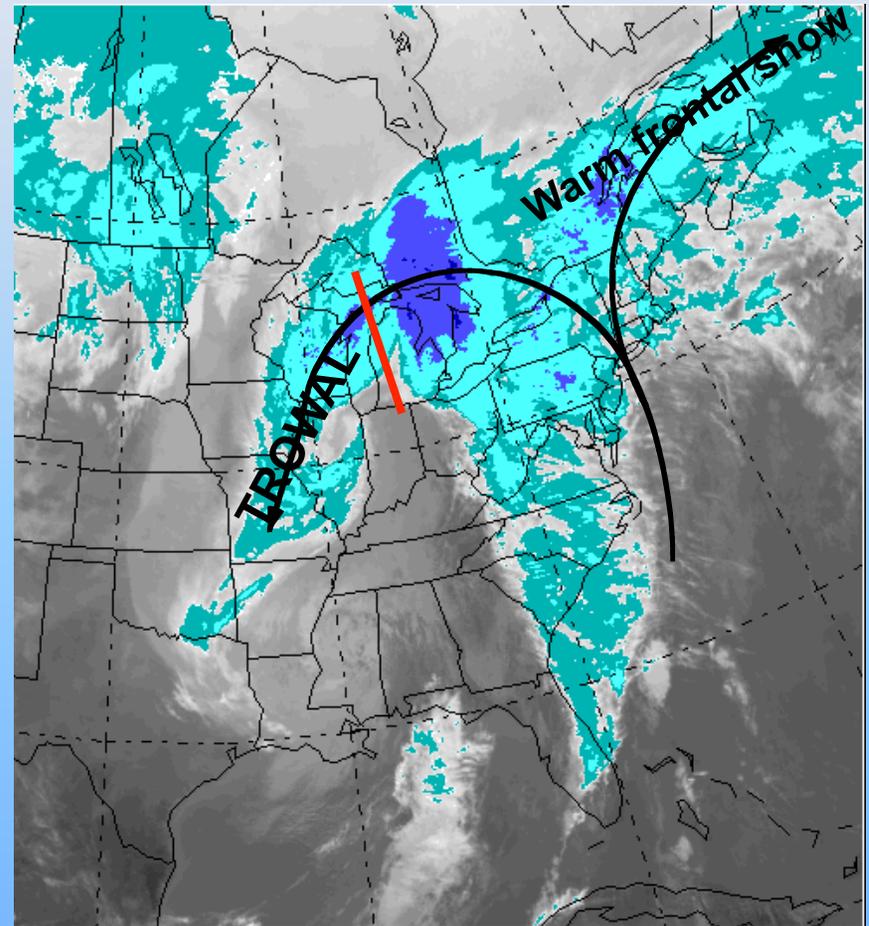


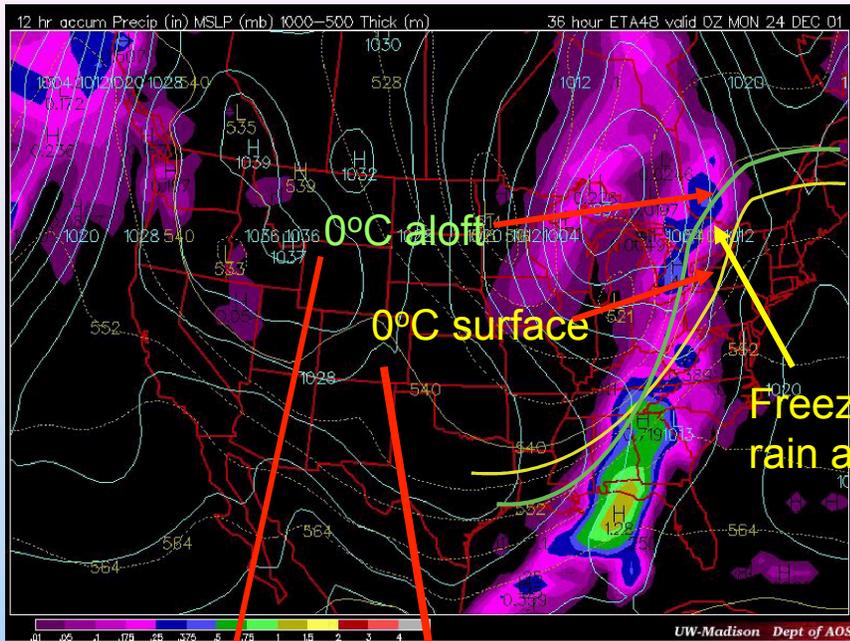
Image courtesy of the Department of Atmospheric Sciences  
University of Illinois at Urbana-Champaign

Heaviest snowfall normally occurs north of the warm front and below the TROWAL (trough of warm air aloft), which appears on satellite images as the “wrap around” part of the comma cloud.

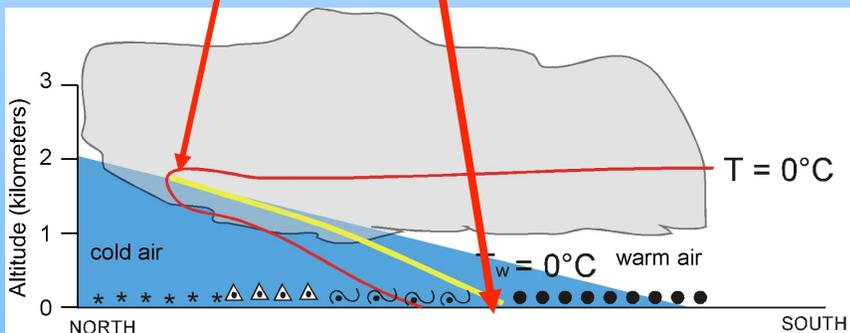


Heavy snow region





Courtesy of the Department of Atmospheric and Oceanic Sciences University of Wisconsin-Madison



## Steps in snow forecasting:

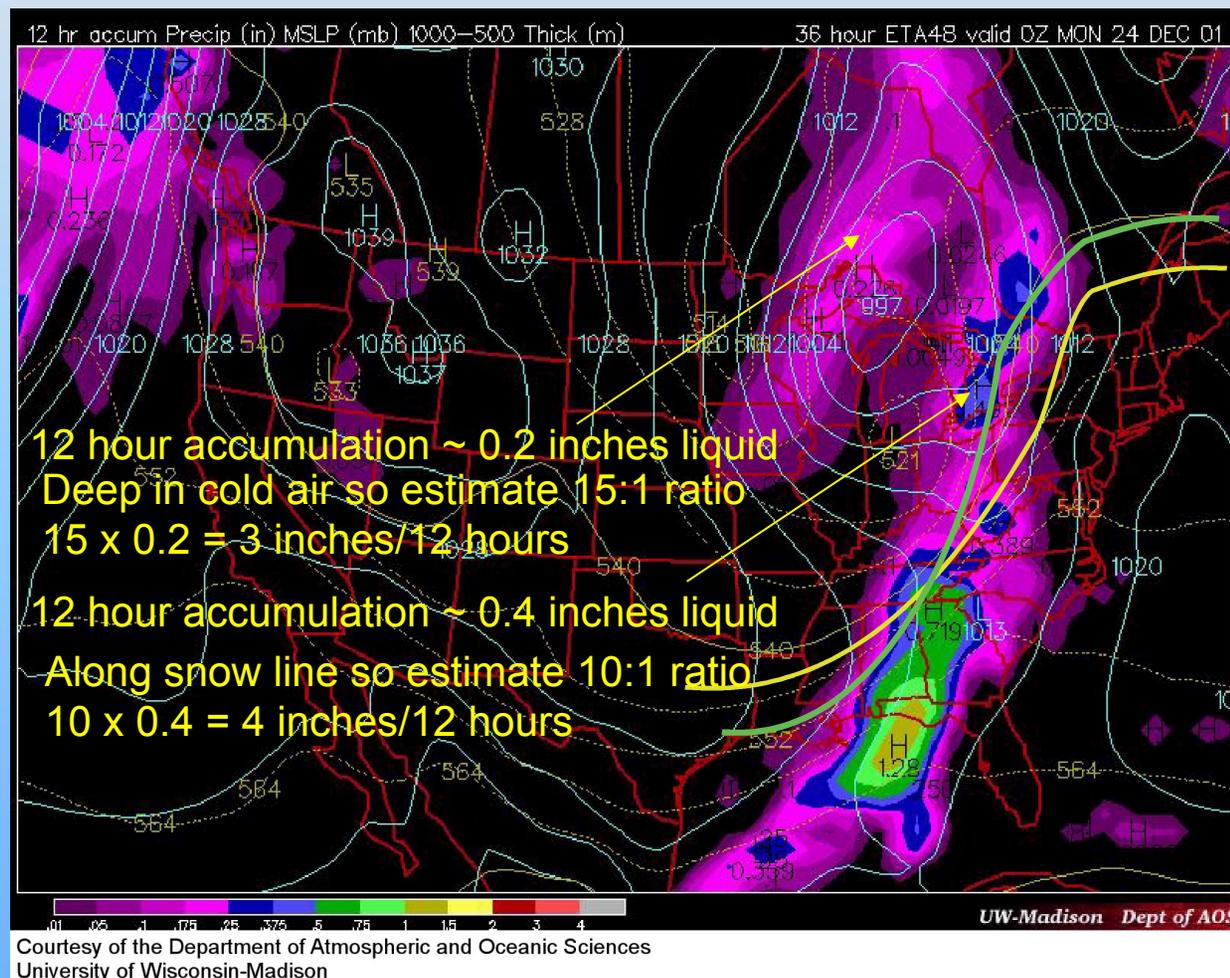
- 1) Identify the southern boundary of the snow line. South of this line, the precipitation may be rain or freezing rain (sleet accumulates, considered "snow").

### Technique:

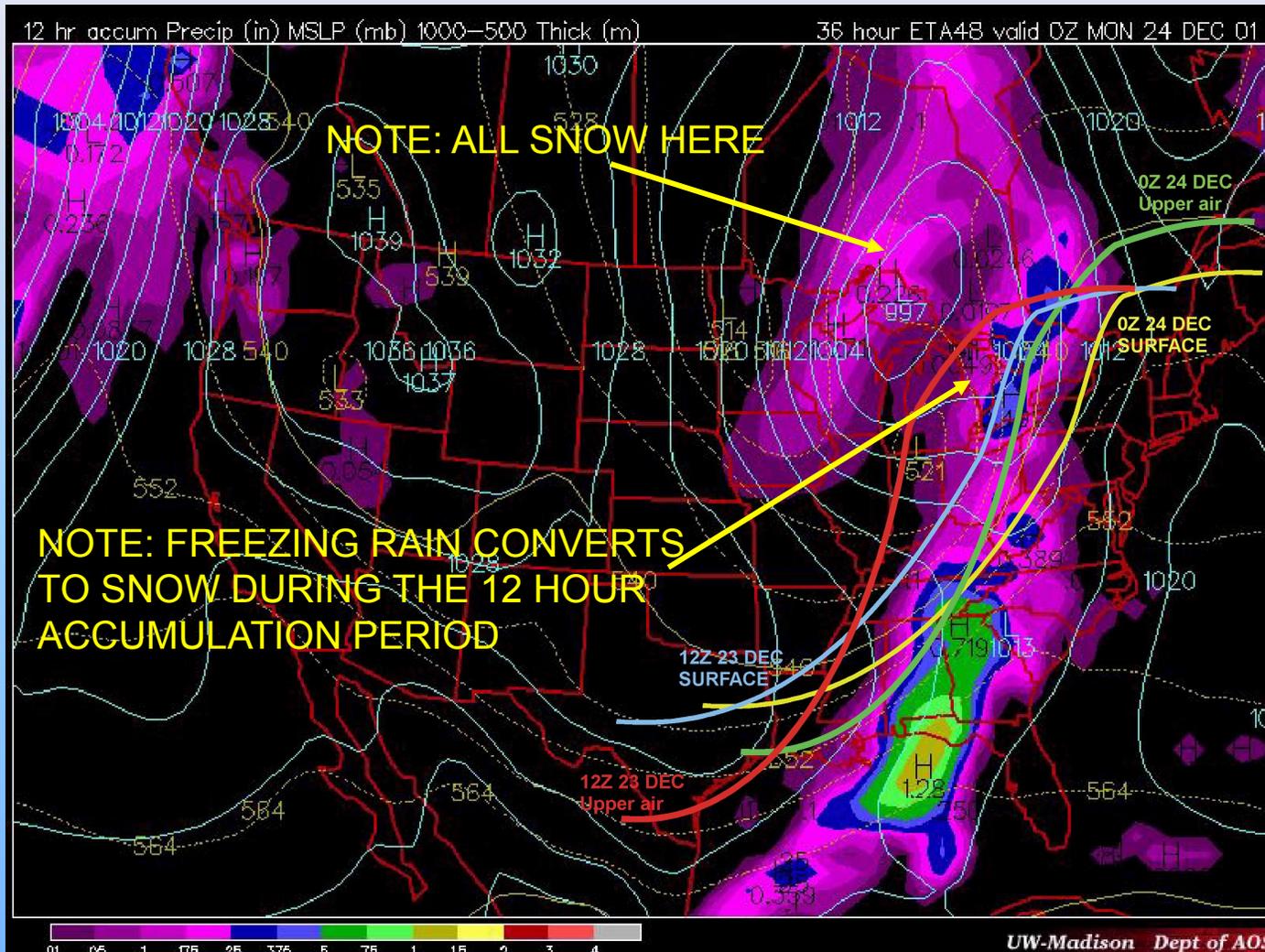
- 1) Plot surface 0°C wet bulb temperature isotherm (temperature is OK if wet bulb is not available).
- 2) Plot cross sections of wet bulb temperature through model predicted region of precipitation where you believe snow may be possible.
- 3) From cross sections, identify the level where the 0°C wet bulb temperature isotherm is displaced furthest north from its surface position.
- 4) Plot a horizontal map of the 0°C wet bulb temperature isotherm at that level. Zone between the surface and mid-level 0°C wet bulb temperature isotherm is likely freezing rain zone. Snow will be north (or northwest) of that point with heaviest snow along the boundary

Step 2: Examine the model quantitative precipitation forecasts for liquid equivalent precipitation in the snow region you identified in step 1.

Step 3: Convert these to snowfall using a snow to liquid ratio based on the storm track. Adjust this initial estimate based on how far the snow is displaced toward the cold air (raise the ratio if the snow is in colder air, lower near the snow line).



Keep in mind that the 0°C surface line and the 0°C aloft line are for an instant in time at the END of the 12 hour precipitation accumulation period. You have to go back and look at the position of these lines at the BEGINNING of the forecast period as well to estimate where the precipitation will be snow, mixed snow/rain, freezing rain, or rain.



Courtesy of the Department of Atmospheric and Oceanic Sciences  
University of Wisconsin-Madison

## STEP 4: Establish the uncertainty

### 1) Examine the other models (RUC, GFS, MM5, WRF etc)

How much does the storm track differ? (uncertainty in location)

How much does the forecast precipitation differ (uncertainty in amount)

How does the timing differ (uncertainty in onset and end of precipitation)

Is one or more models “slowing down” the storm, which may lead to additional accumulation?

### 2) Are there any factors that could significantly modify the model estimate?

Is the ground warm so that snow will melt on contact?

Are there local features such as hills, water bodies that can locally enhance snowfall?

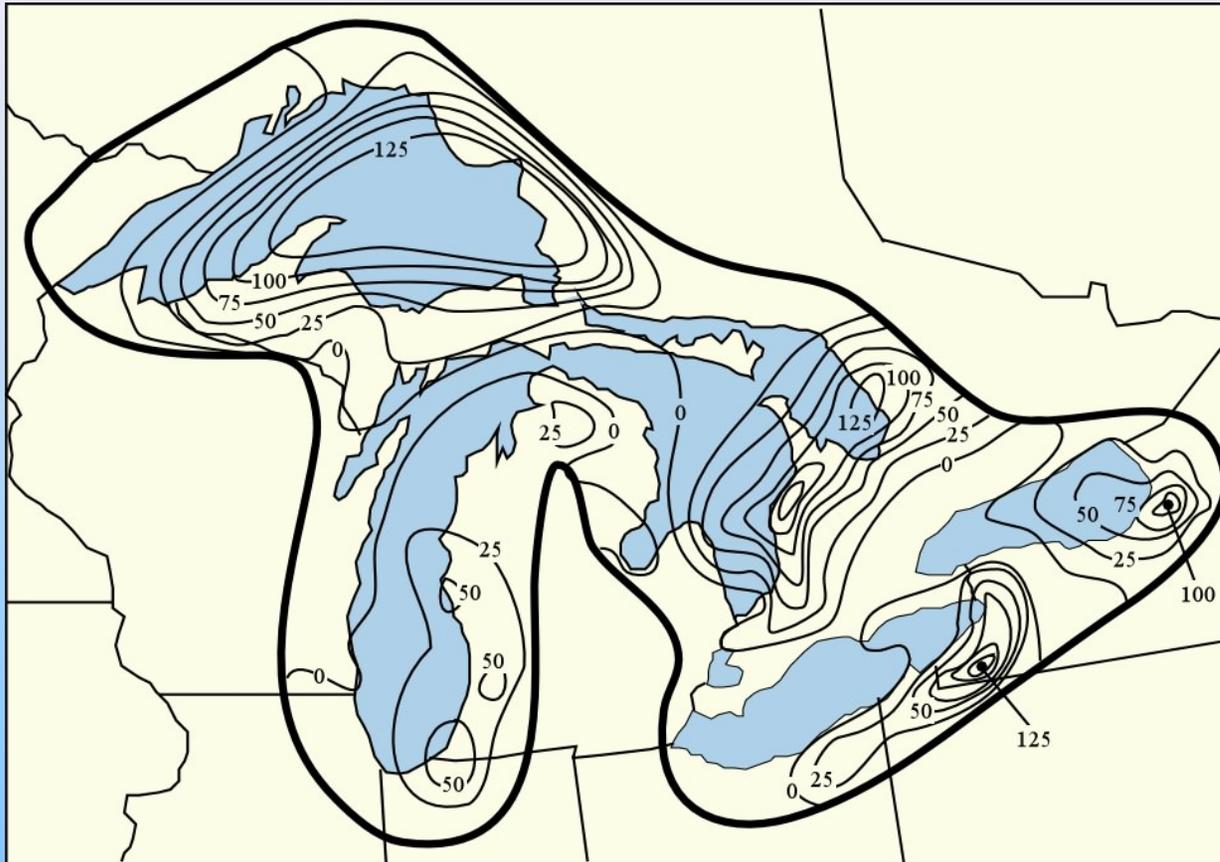
Is there potential for a delay in onset because very dry air is present near the surface?

Is there potential for an early termination of snow because of an advancing dry slot aloft?

## STEP 5: Make a forecast that accounts for uncertainty

“Snowfall will range from 3-6 inches across most of the area, although locally heavier snow of 4-8 inches is possible. Snow will begin between 8 pm and midnight and will be heaviest north of I-74, although snow is possible as far south as I-72.”

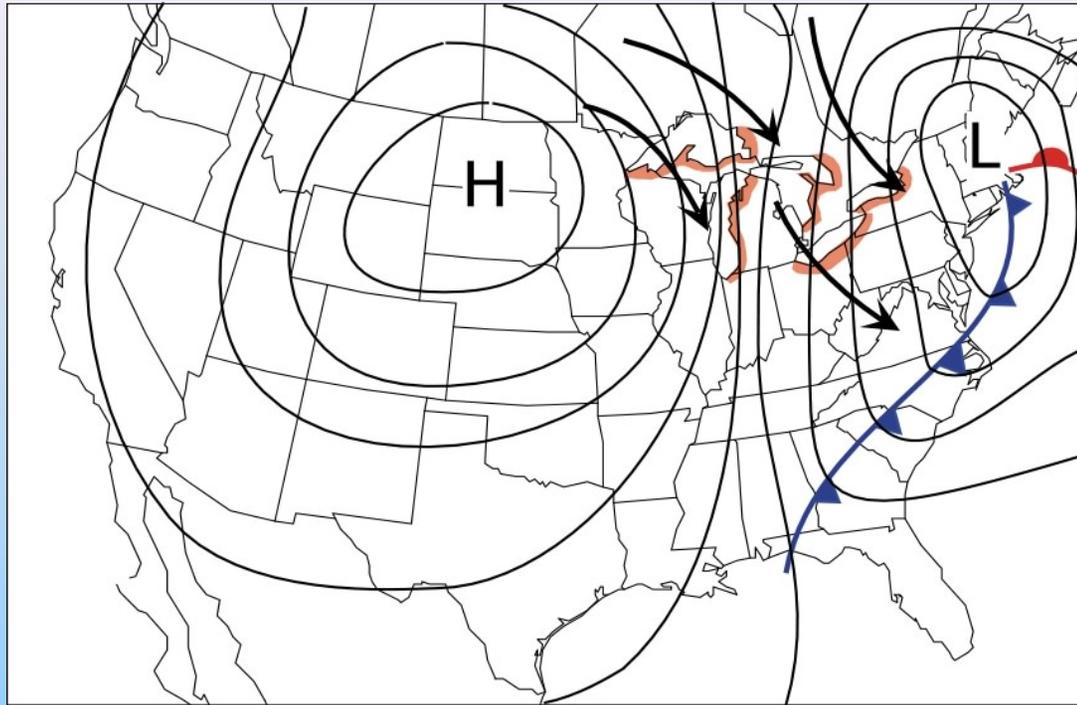
# The Great Lakes Region



Courtesy of the Journal of Great Lakes Research

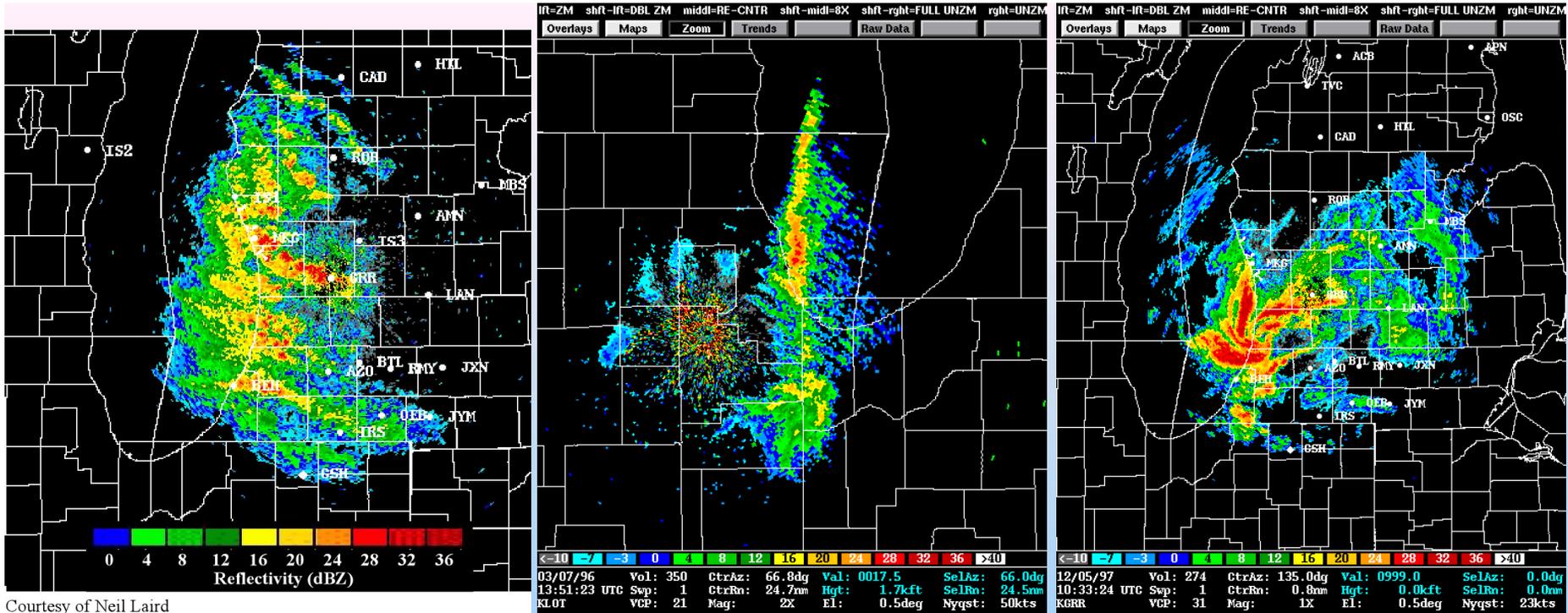
Additional wintertime precipitation (mm liquid) attributable to Great Lakes

## Common Weather Pattern For Lake Effect Storms



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Lake effect storms impact major metropolitan areas: Chicago, Milwaukee, Detroit, Cleveland, Erie, Buffalo; and many smaller communities.



Courtesy of Neil Laird

Widespread – Roll circulations  
(strong winds across lake)

Mid-lake or shore parallel band  
(weak winds or strong winds  
along lake axis)

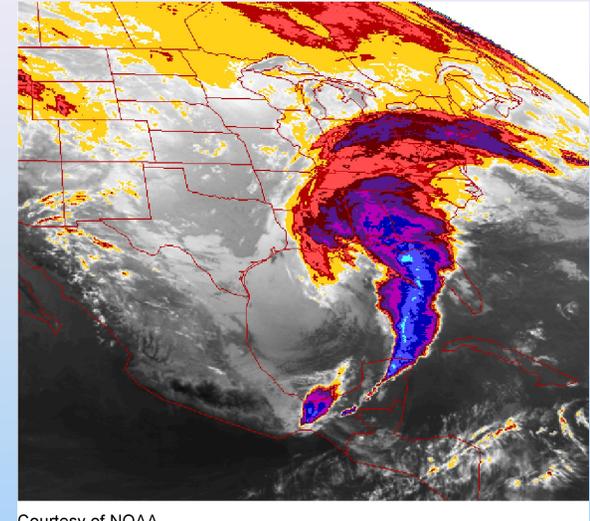
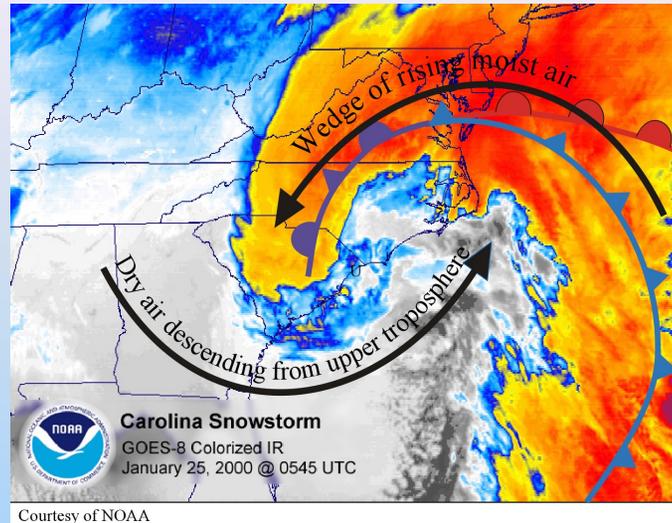
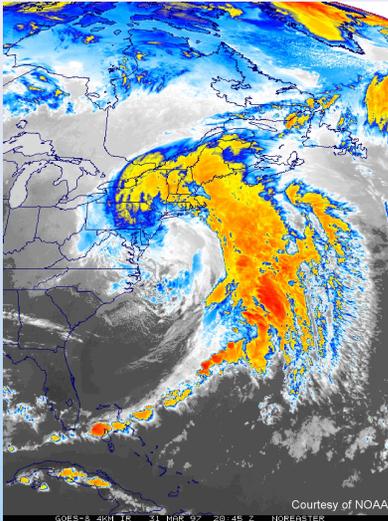
Vortices  
(weak winds, long fetch  
over lake)

The wind speed and orientation relative to a lake determines the morphology of lake effect snows and determines which locations around the lakes will receive snow.

Lake effect snow is typically low density (15:1 to 30:1). It falls at rates varying from about 0.5 inches per hour (widespread) to 2 inches per hour (mid-lake, vortex). depending on the organization

TOTAL ACCUMULATION: (time lake effect is expected for region) × ( average rate based on organization)

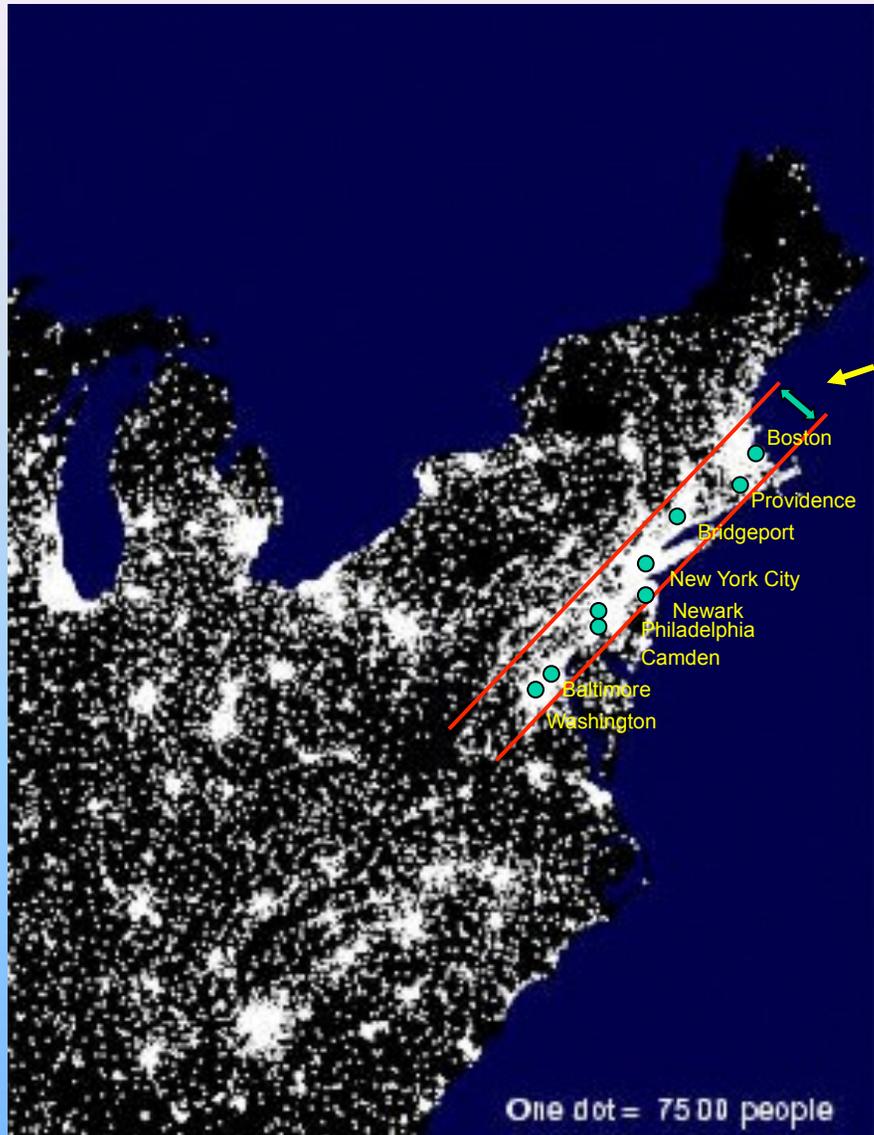
# EAST COAST AND APPALACHIAN MOUNTAINS



The primary snow producers are cyclones called “Nor’easters”

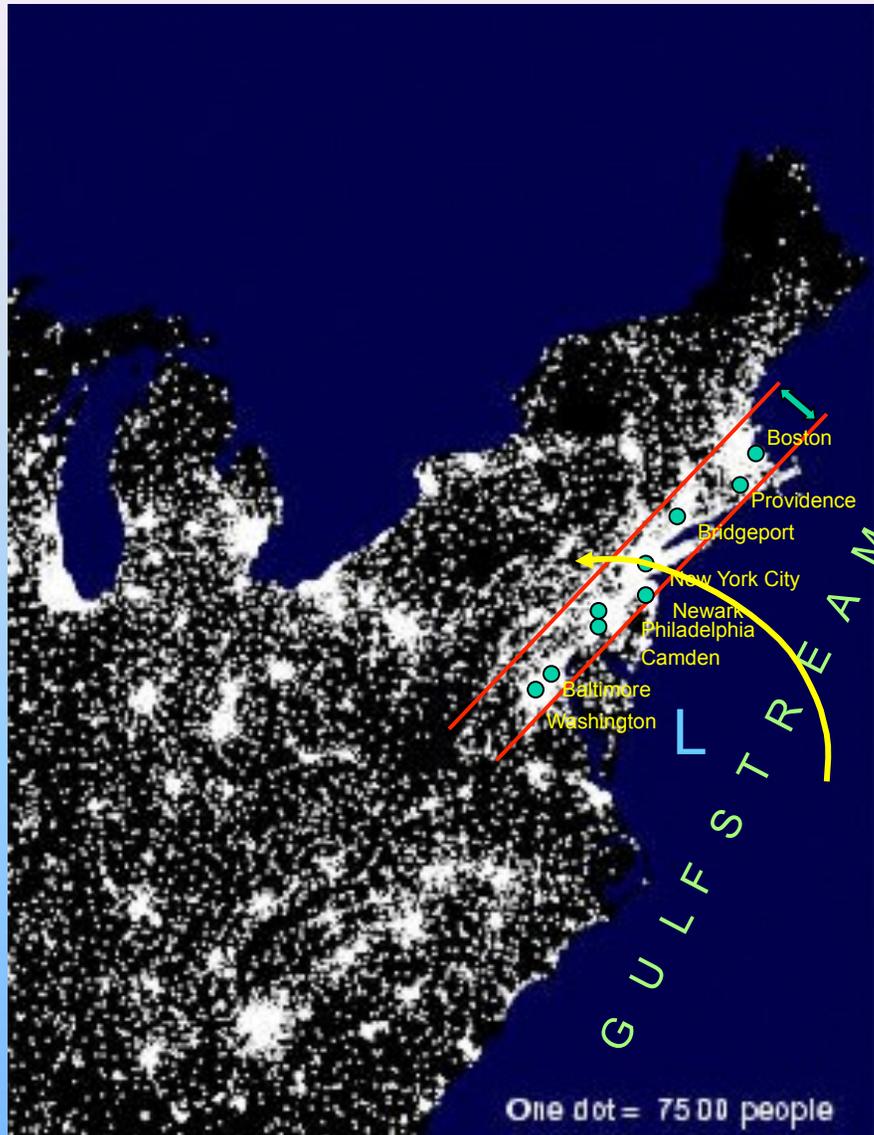
Ocean provides a vast source of moisture for Nor’easters. As a result, Snowfall rates can be very high, often 1-3 inches per hour.

Appalachian mountains provide a source of lift in addition to the rising motion associated with the storm’s fronts and larger scale circulations. Within Appalachians, it is not uncommon for several feet of snow to accumulate during a strong Nor’easter.



The most difficult problem in forecasting snowfall for the East Coast is the POSITION OF THE RAIN-SNOW LINE relative to the major population centers.

Forecast error in position of the rain-snow line affects the actions of millions of people, schools, cities, the federal government, the world financial centers, major airports.



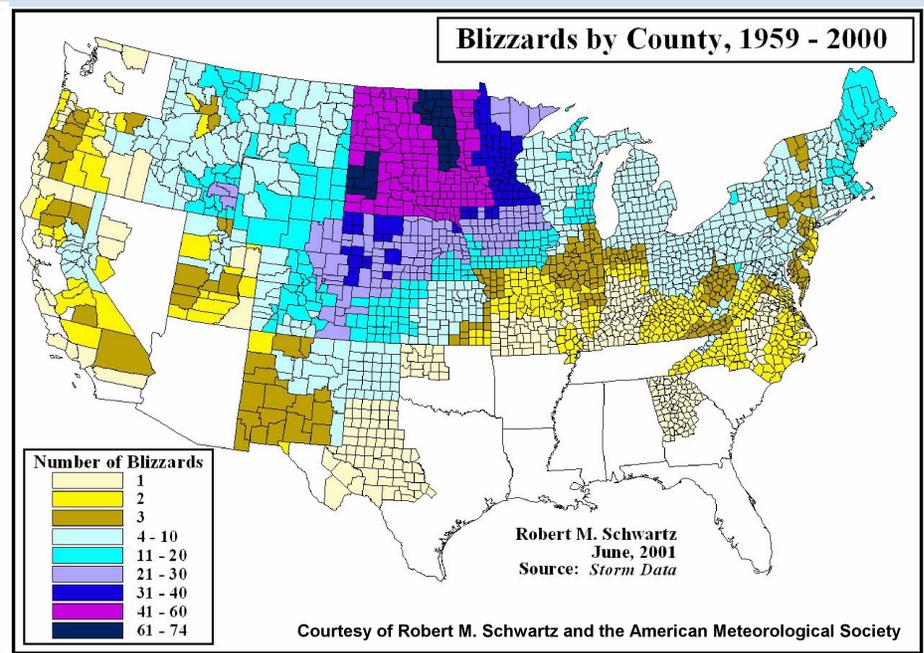
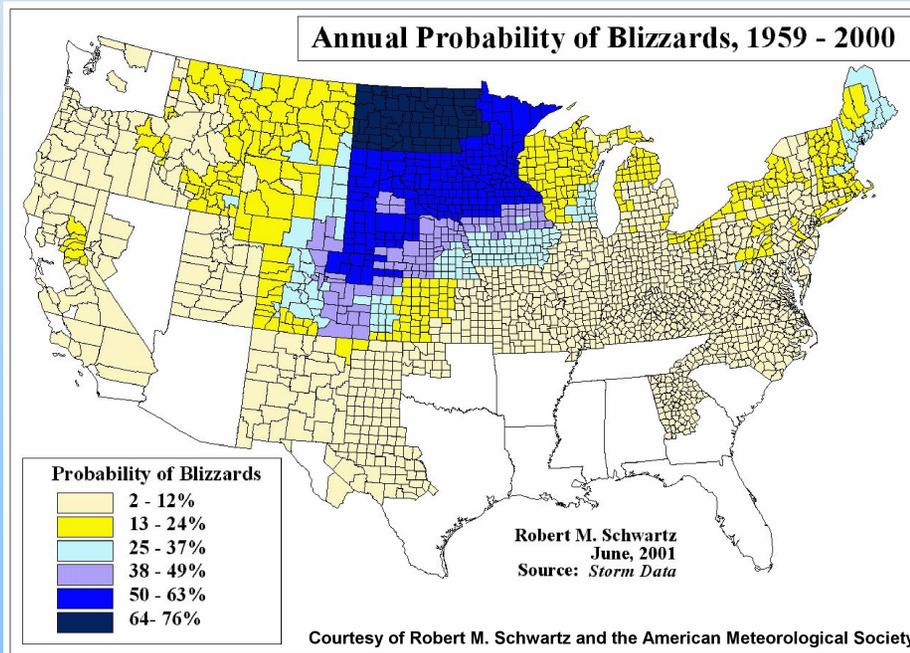
Fundamental problem is that near-surface air is warmed by heat flux from ocean, particularly as it passes over the Gulfstream.

As a result, near shore temperatures are often above freezing, while temperatures inland are below freezing

This is one of the most difficult snow forecast problems in the U.S. and has been studied by NCEP in some detail after several bust forecasts. Forecast model solutions are very sensitive to sea surface temperature and surface heat flux parameterizations.

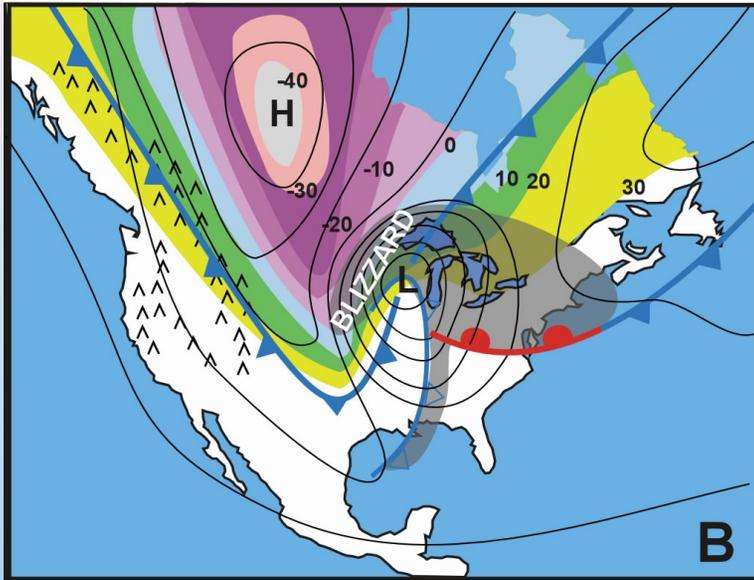
For Nor'easters, model solutions must be examined very carefully, and even then, some hedging is always necessary since the scale of the problem is at or below the resolution of operational forecast models.

**Blizzard: Winds exceed 30 knots and falling or blowing snow reduces visibility to ¼ mile or less**



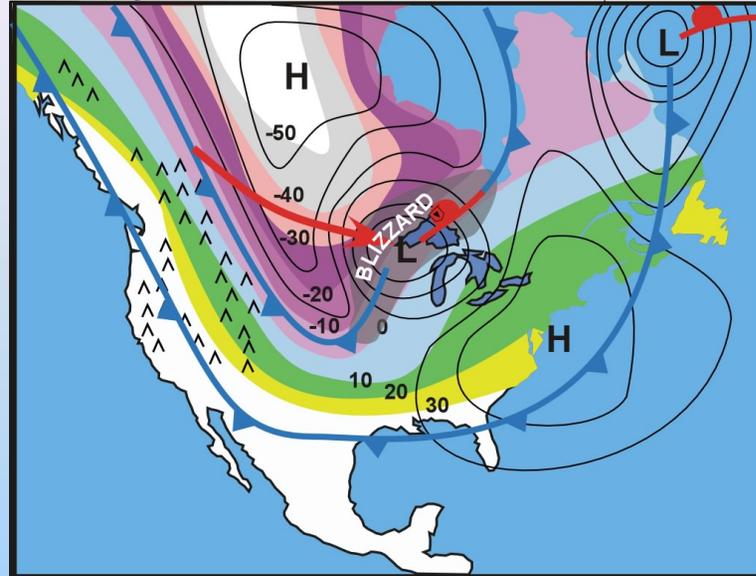
Temperature is not in official criteria for a blizzard, although extremely cold temperatures are a dangerous component of blizzard conditions.

Colorado cyclone with arctic front



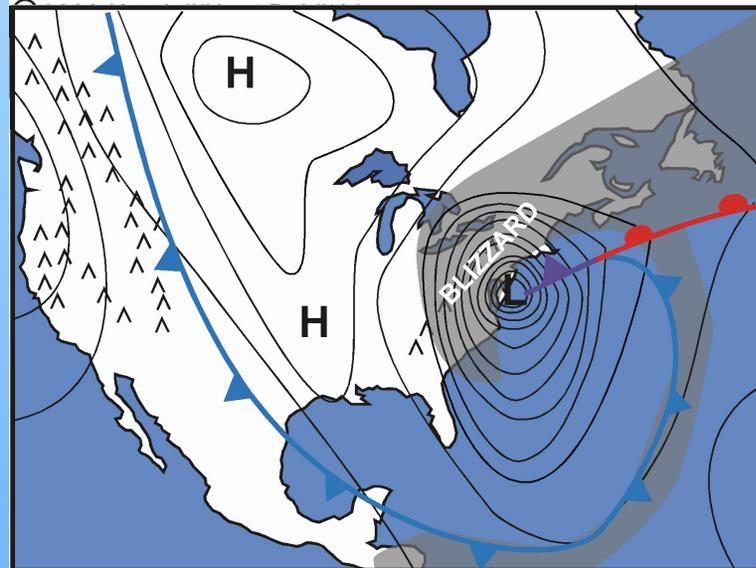
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Alberta Clipper cyclone and arctic front



Surface pressure (and temperature) Patterns during blizzards

Nor'easter cyclone along East Coast



**Freezing precipitation** is rain or drizzle that freezes on surfaces and leads to the development of an ice glaze.



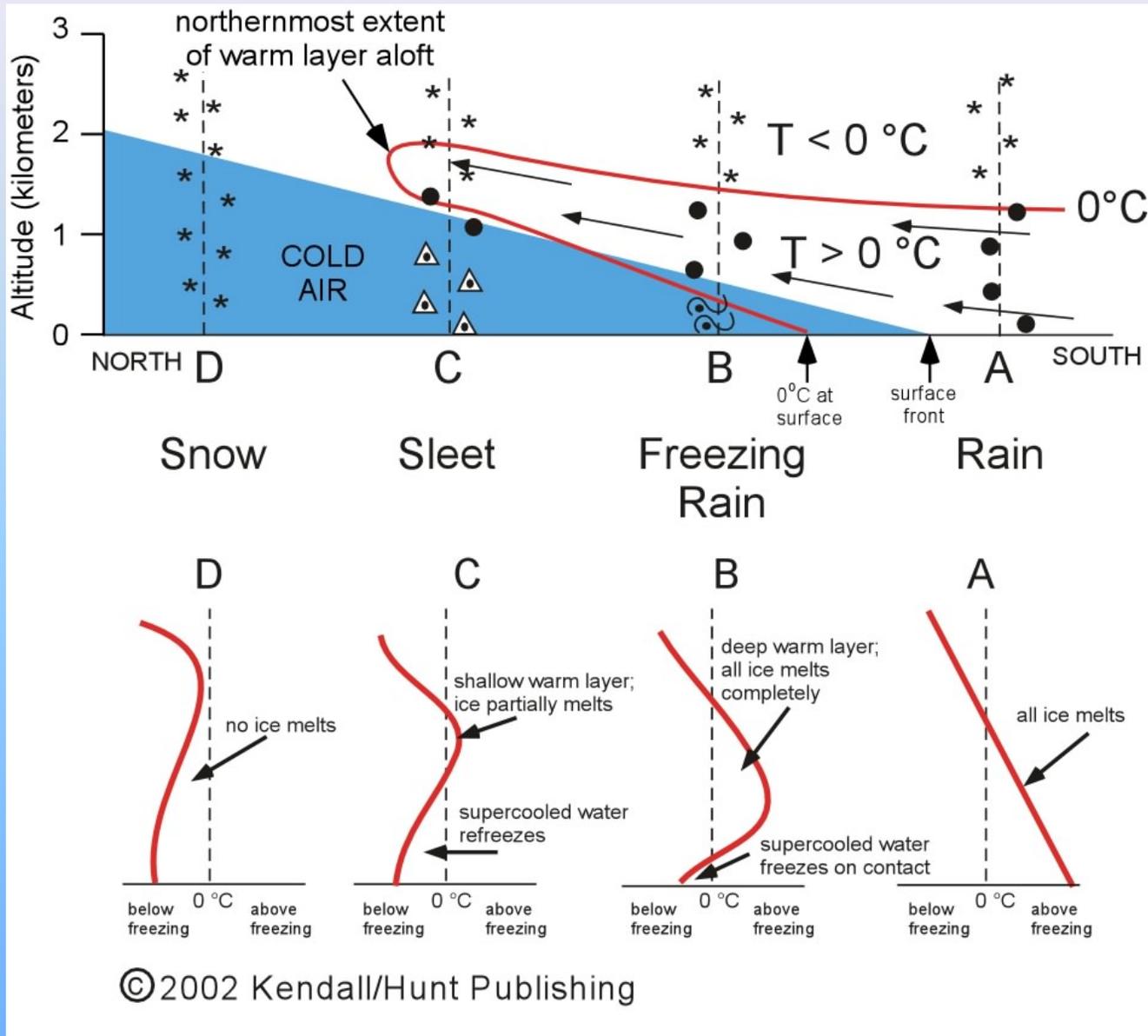
Courtesy: Environment Canada



Courtesy: NWS/NOAA

# Two cloud microphysical mechanisms that lead to the formation of freezing rain:

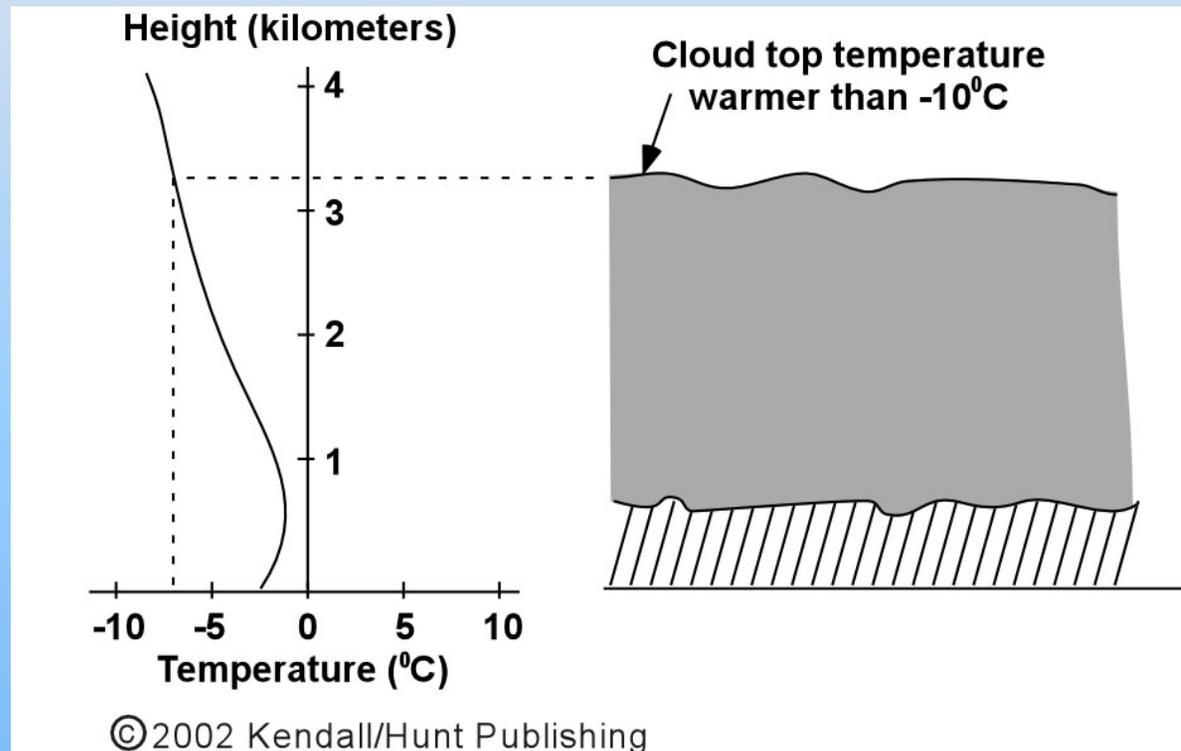
## 1. Warm layer aloft above surface freezing layer



## Two cloud microphysical mechanisms that lead to the formation of freezing rain:

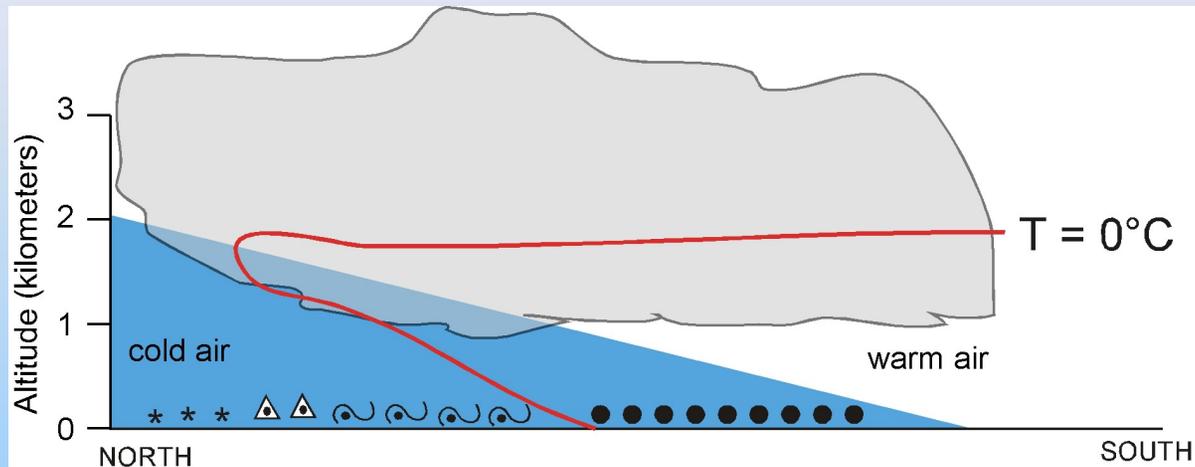
2. Cloud top temperature  $> -10^{\circ}\text{C}$  and part or all of atmosphere (including surface) below freezing

“Supercooled warm rain process” – droplets grow to drizzle size by collision and coalescence within cloud



Serious aircraft icing hazard aloft and surface transportation hazard

The importance of the wet bulb temperature profile to the structure of the warm layer aloft:

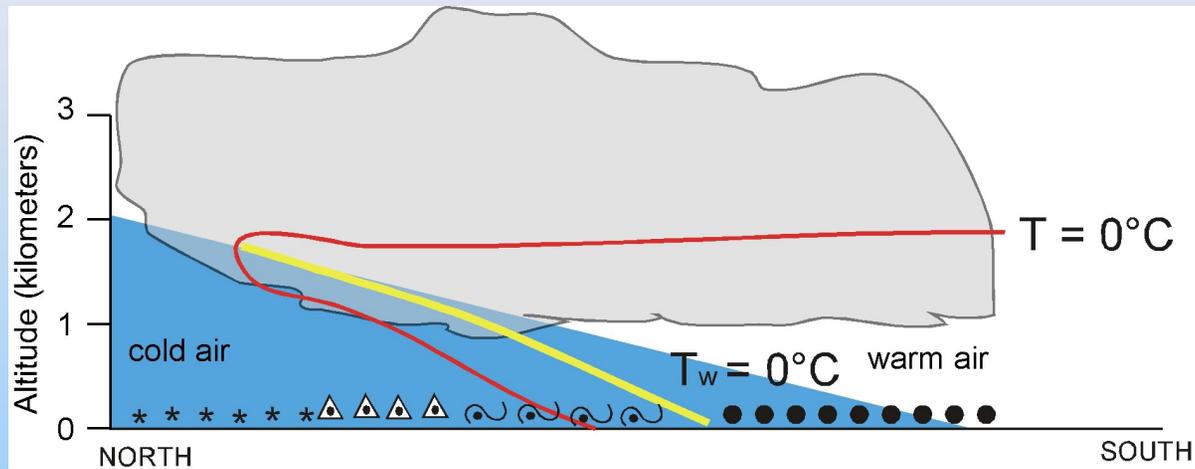


Suppose that:

- 1) the air above the front was saturated in cloud and nearly saturated below cloud
- 2) cold air below the front initially had a low RH ( $\sim 40\%$ )
- 3) precipitation began to fall to the ground below the cloud, initially arriving at the surface with the types indicated based on the temperature.

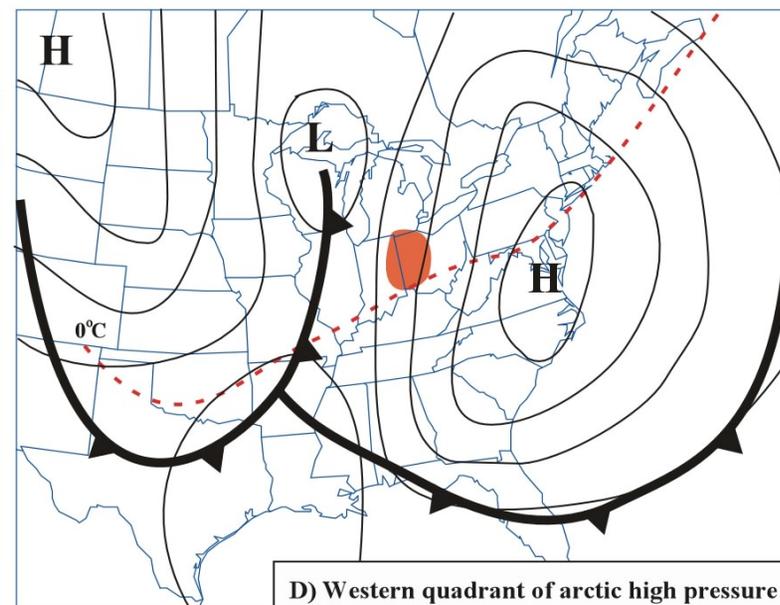
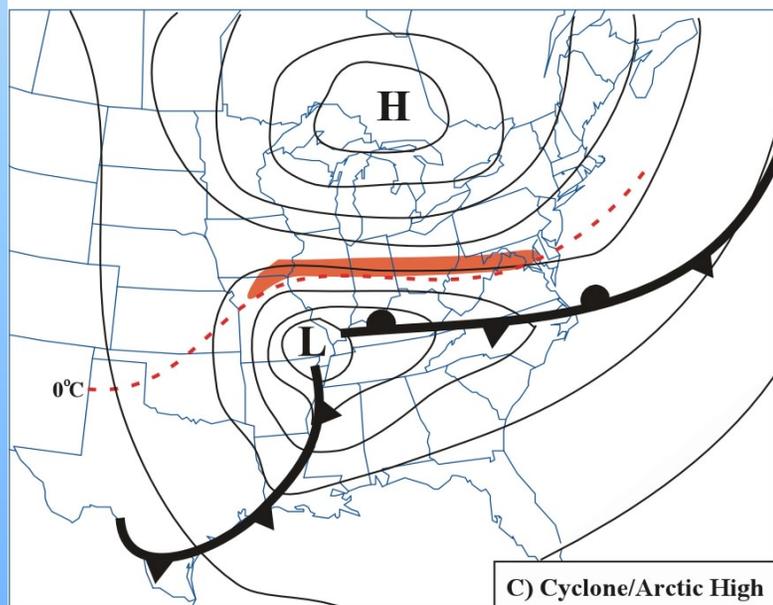
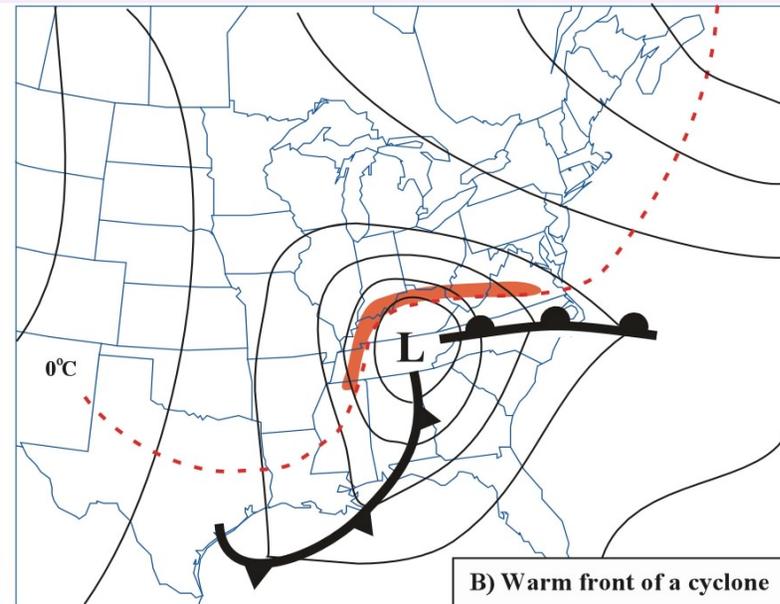
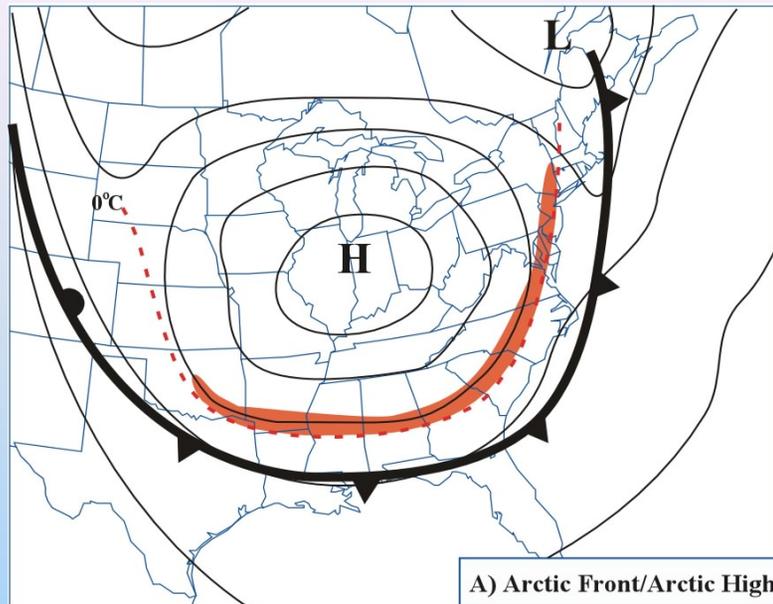
What would happen to the distribution of precipitation type at the surface with time?

The importance of the wet bulb temperature profile to the structure of the warm layer aloft:

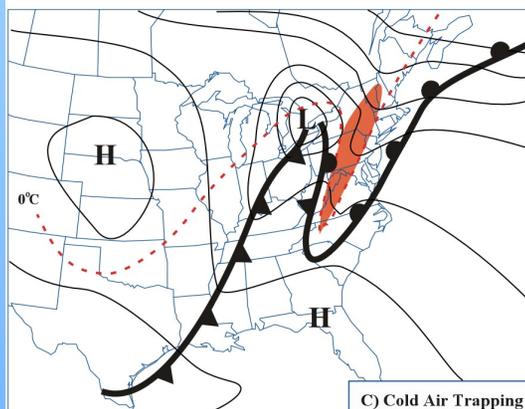
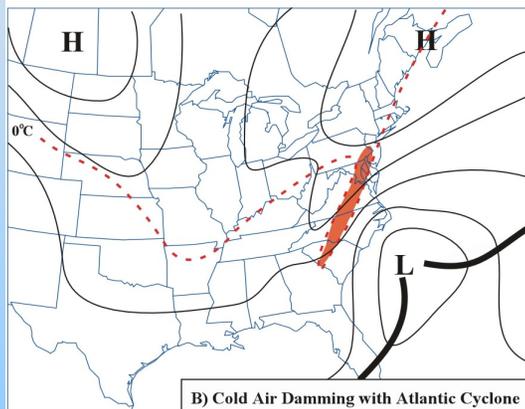
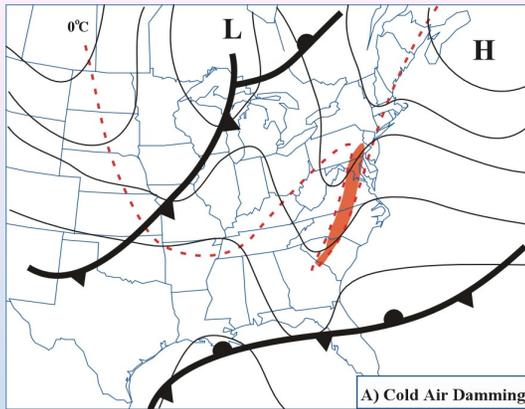


Air below the front would cool to its wet bulb temperature changing the distribution of surface precipitation.

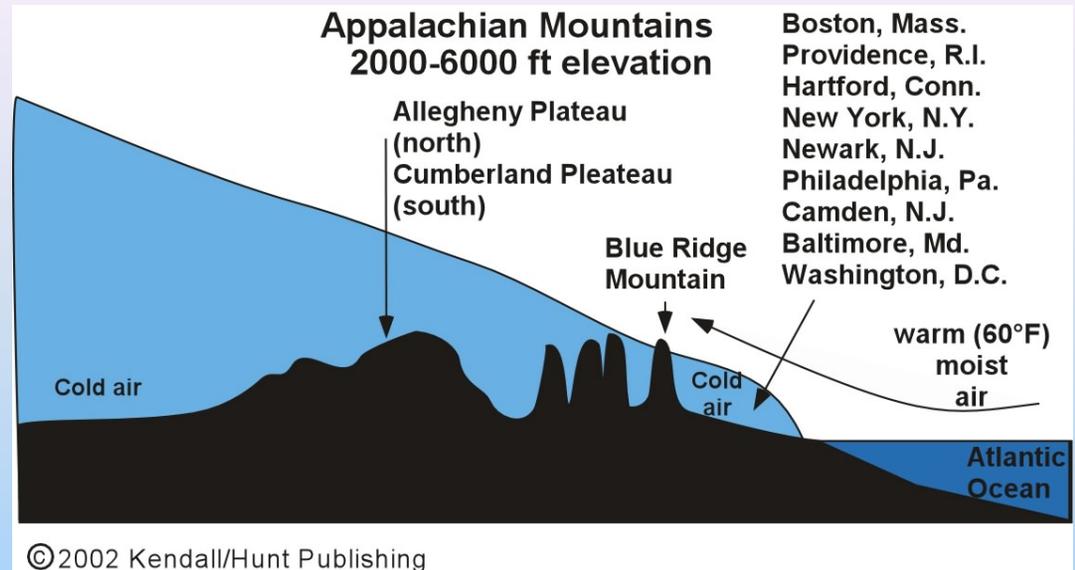
# Typical location where freezing precipitation forms relative to fronts



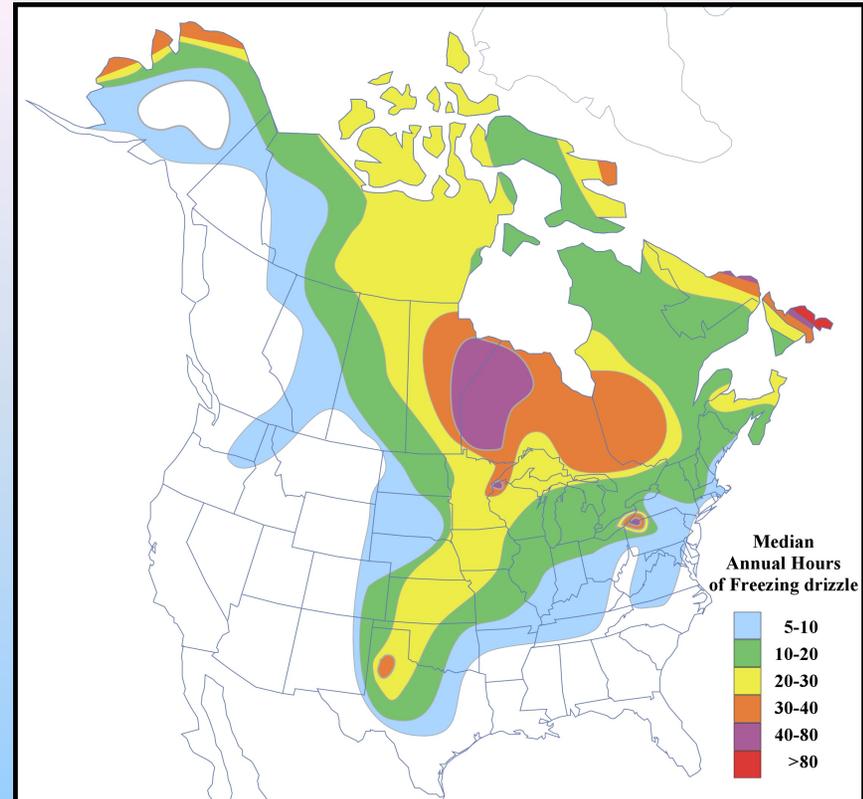
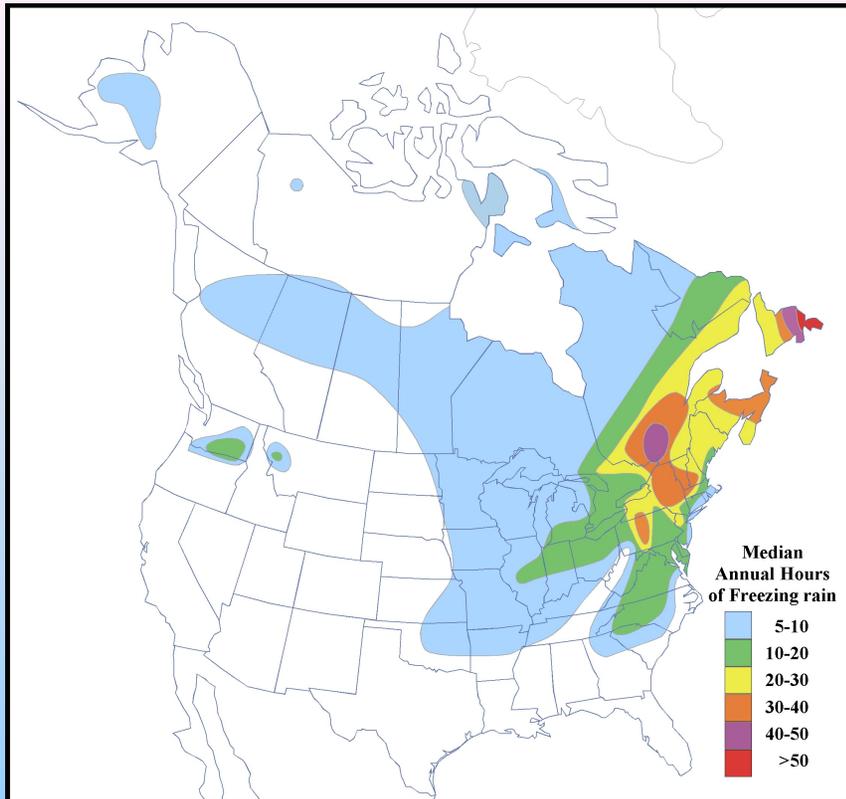
Courtesy of the American Meteorological Society



Courtesy of the American Meteorological Society



Cold air damming east of the Appalachian Mountains and cold air trapping within the Appalachian mountain valleys can lead to freezing rain during the weather patterns shown on the left.



**The distribution of hours of freezing rain and drizzle across North America**

What is the relationship between the weather patterns and the climatology?

Two factors determine whether freezing rain will be a nuisance or a disaster:

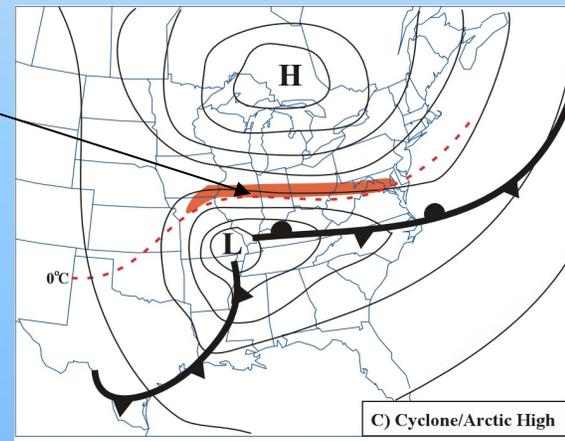
1. Duration of freezing rain
2. Wind during and after the ice accumulation

### 1. Duration

Freezing rain rarely occurs as heavy precipitation. Even when it does, the supercooled rain cannot freeze fast enough to accumulate at a rate much greater than a light rain. Of Greater importance is duration.

BUT: Freezing rain occurs in a narrow zone

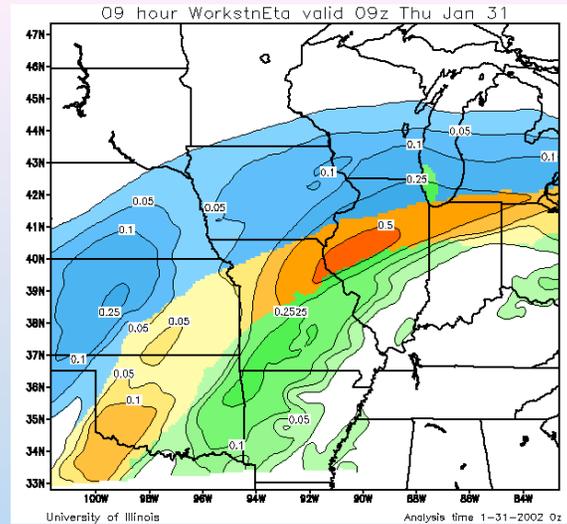
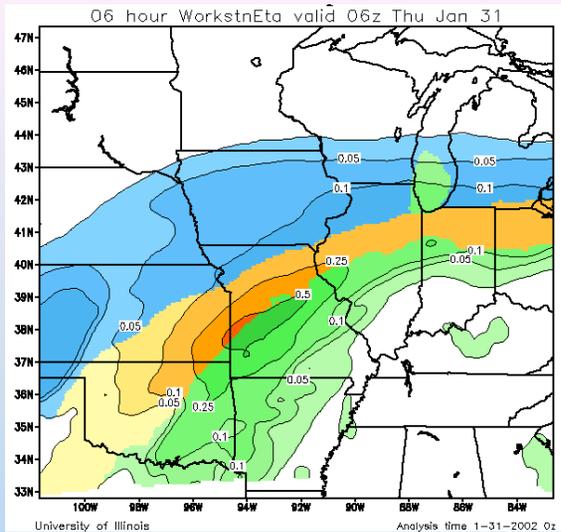
If cyclone/weather system is propagating, zone of freezing rain will shift, so that duration of accumulation will be too short for major destruction.



REQUIREMENT FOR SIGNIFICANT ACCUMULATIONS:

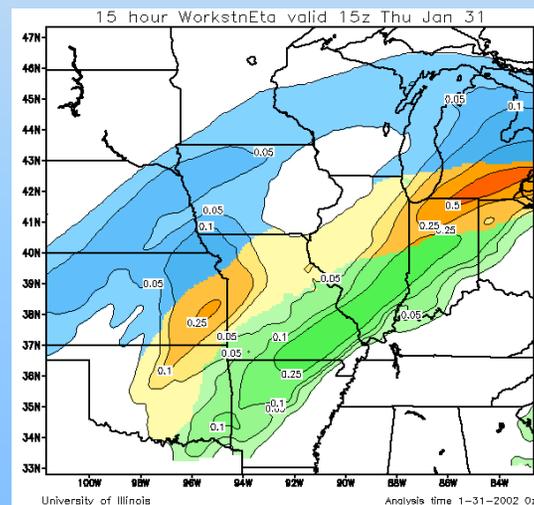
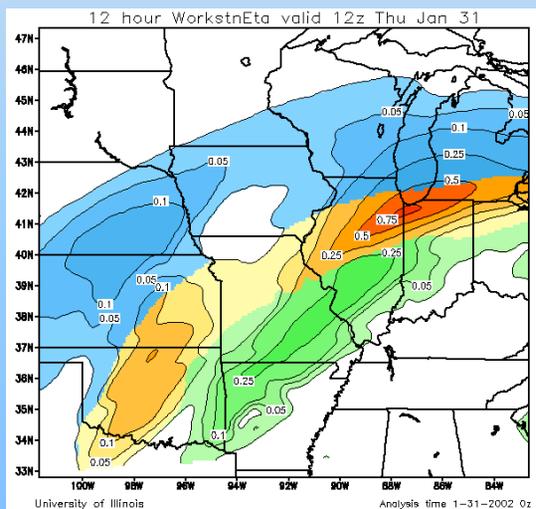
STATIONARITY OF FRONTAL BOUNDARY

NEAR-CONTINUOUS PRECIPITATION DURING THE PERIOD OF STATIONARITY



Blue = snow  
 Orange = Freezing precip  
 Green = Rain

January 31, 2002



**Example of a weather system that had a near-stationary weather pattern and produced disastrous ice accumulations in several states.**

# EFFECT OF WIND



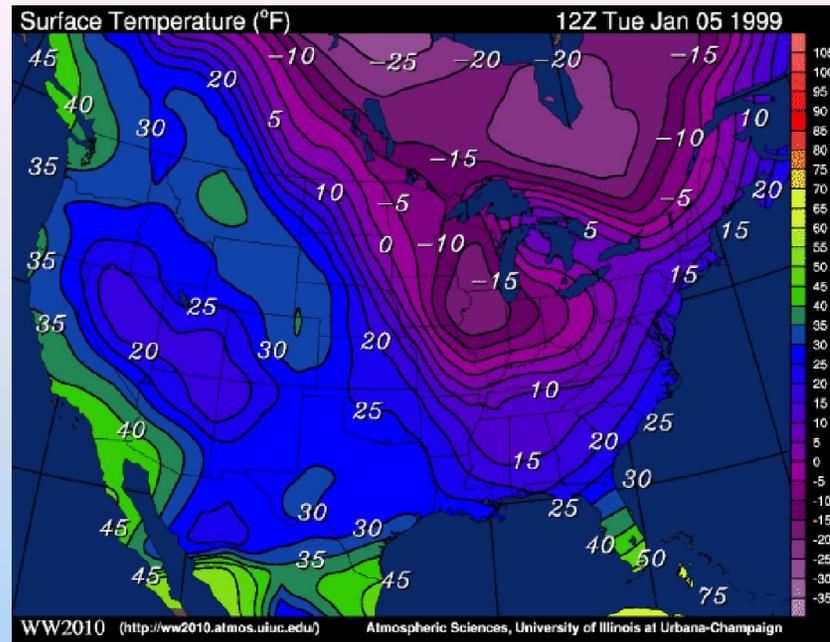
Once structures are coated with ice, their destruction is made easier by wind stress.

Ice storm forecasts should include consideration of wind and discussion of potential problems that may develop if strong winds are expected.

# Extreme Cold

Forecasting dangerous cold involves consideration of both the temperature and the effect of wind on the human body's heat loss.

The "Wind Chill Factor" incorporates these two parameters and is used by the NWS to warn of extreme cold conditions that can lead to Hypothermia and Frostbite.



Courtesy of the Department of Atmospheric Sciences  
University of Illinois at Urbana-Champaign



## Wind Chill Chart



		Temperature (°F)																	
		40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
Wind (mph)	5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
	10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
	15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
	20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
	25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
	30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
	35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
	40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
	45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
	50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
	55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98	

Frostbite Times ■ 30 minutes ■ 10 minutes ■ 5 minutes

$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Courtesy of NOAA

Where, T= Air Temperature (°F) V= Wind Speed (mph)

Effective 11/01/01