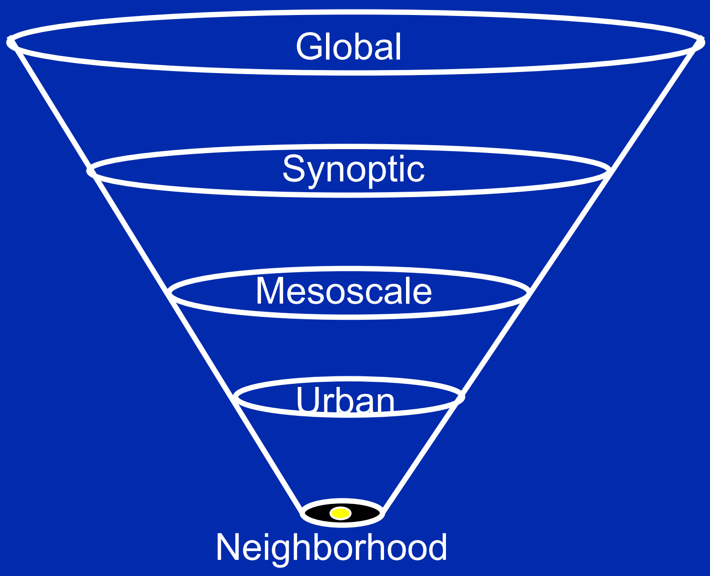
# Meteorology and Air Quality

- Processes that influence air quality
  - Sunlight
  - Horizontal dispersion
  - Vertical mixing
  - Transport
  - Clouds and precipitation
- Large scale to local scale

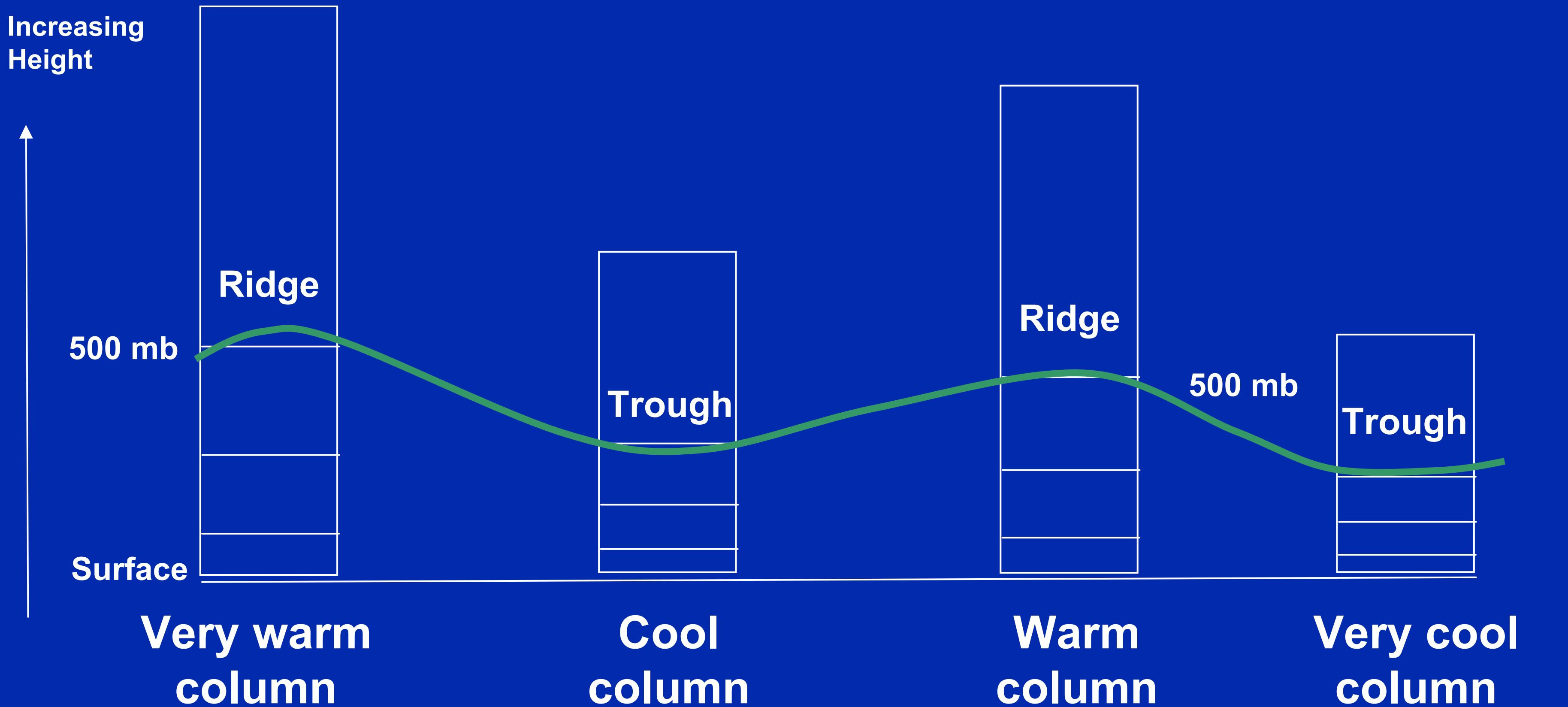


# Basic Weather

- Aloft ridges and troughs
- Rising and sinking air
- Surface highs and lows
- Ridges, troughs, and temperature soundings
  - Inversions
  - Stability
  - Mixing
- Clouds and precipitation
- Winds
  - Synoptic scale
  - Meso- and local-scale
  - Transport (surface and aloft)

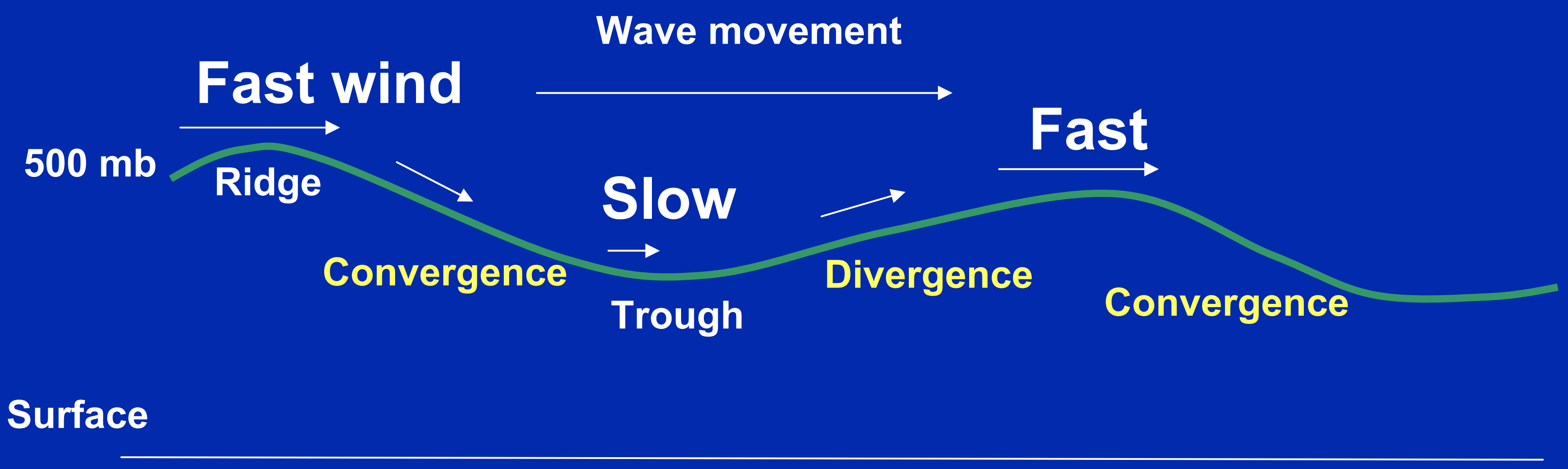
# Aloft Ridges and Troughs (1 of 3)

- Mountains and valleys of warm and cool air
- The height of the 500-mb pressure altitude depends on the relative temperature of the column



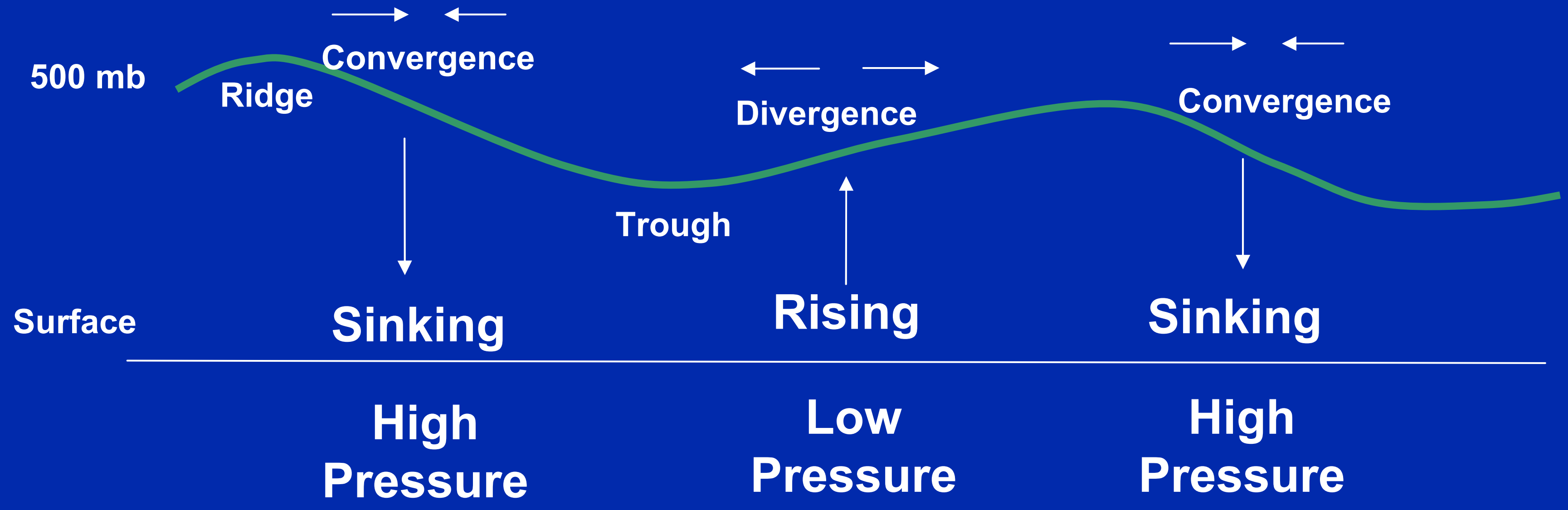
# Aloft Ridges and Troughs (2 of 3)

- Waves (ridges and troughs) generally move west to east
- Winds generally travel faster around ridges and slower around troughs
- Areas of aloft convergence and divergence



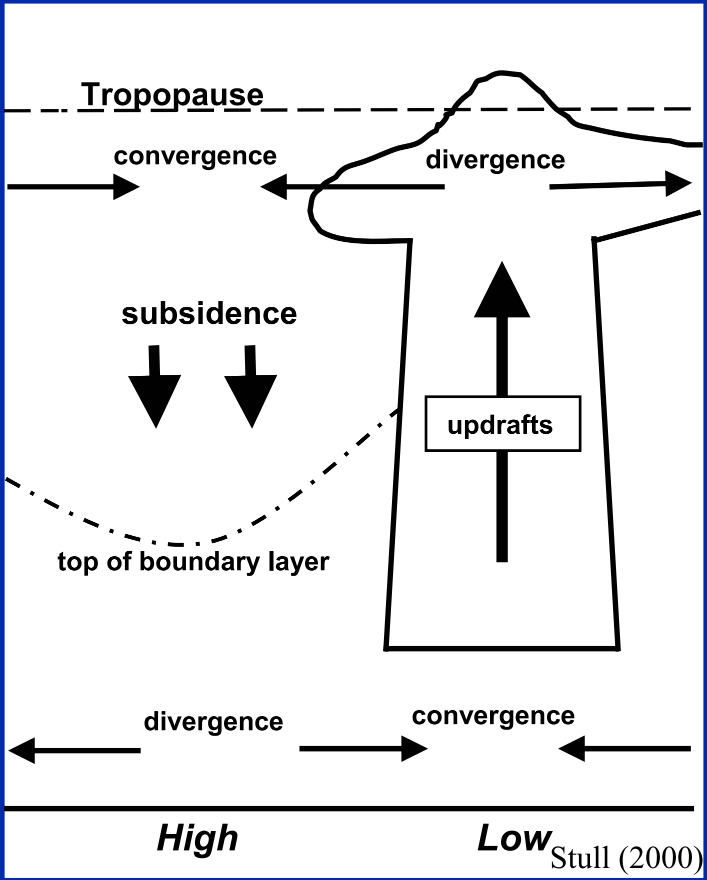
# Aloft Ridges and Troughs (3 of 3)

- Aloft divergence causes rising motion and a surface low
- Aloft convergence causes sinking motion and a surface high
- Surface pressure patterns are offset from aloft patterns



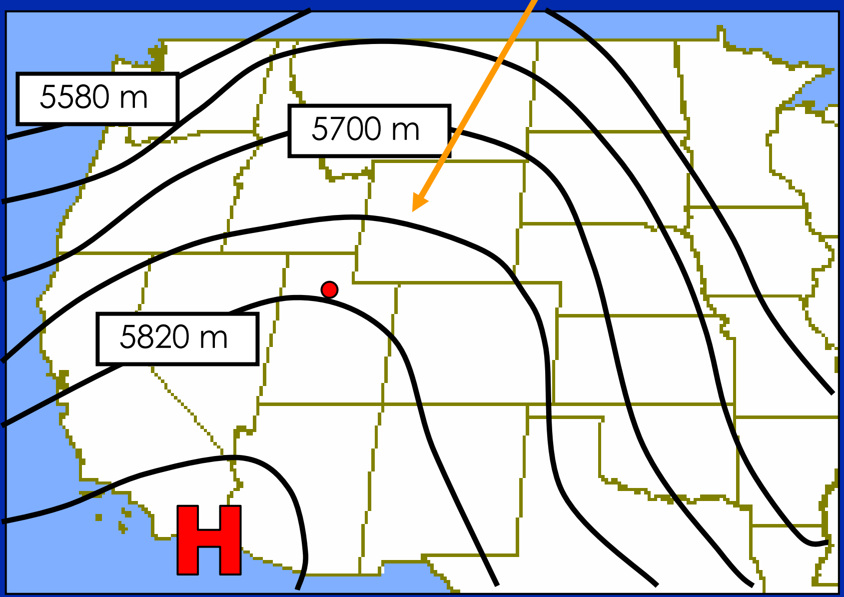
# Rising and Sinking Air

- Sinking motion
  - Warms the air
  - Creates stable conditions
  - Reduces vertical mixing
  - Creates clear skies
  - Associated with poor air quality
- Rising motion
  - Cools the air
  - Creates unstable conditions
  - Increases mixing
  - Causes cloud cover
  - Associated with good air quality

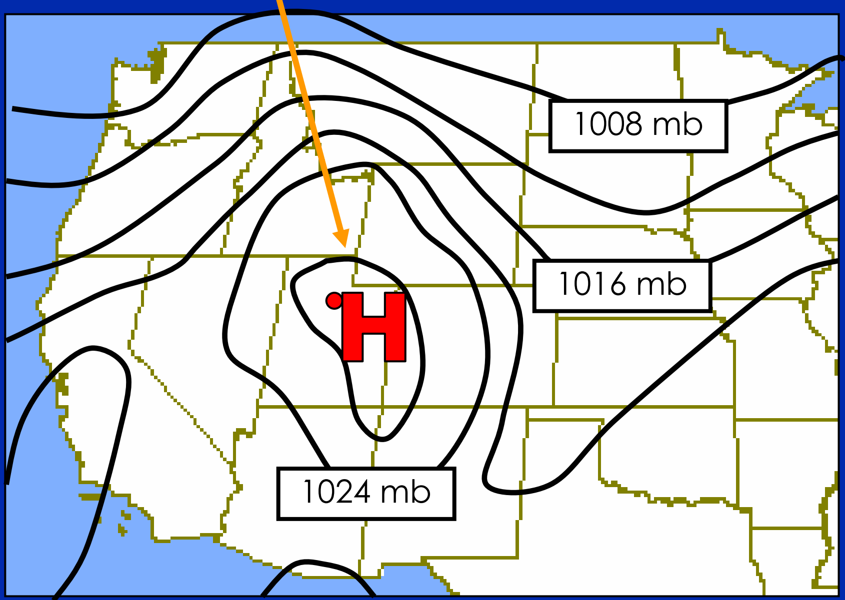


# Surface Highs and Lows – Relationship to Aloft Pattern (1 of 2)

Ridge = Sinking = Surface high




500-mb heights on the afternoon of January 7, 2002 (00Z Jan 8)

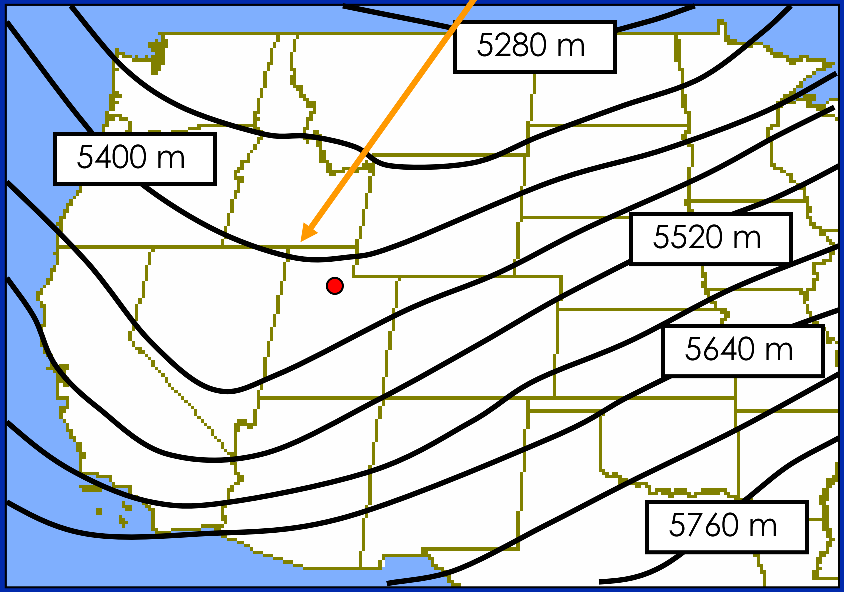



Surface pressure on the afternoon of January 7, 2002 (00Z Jan 8)

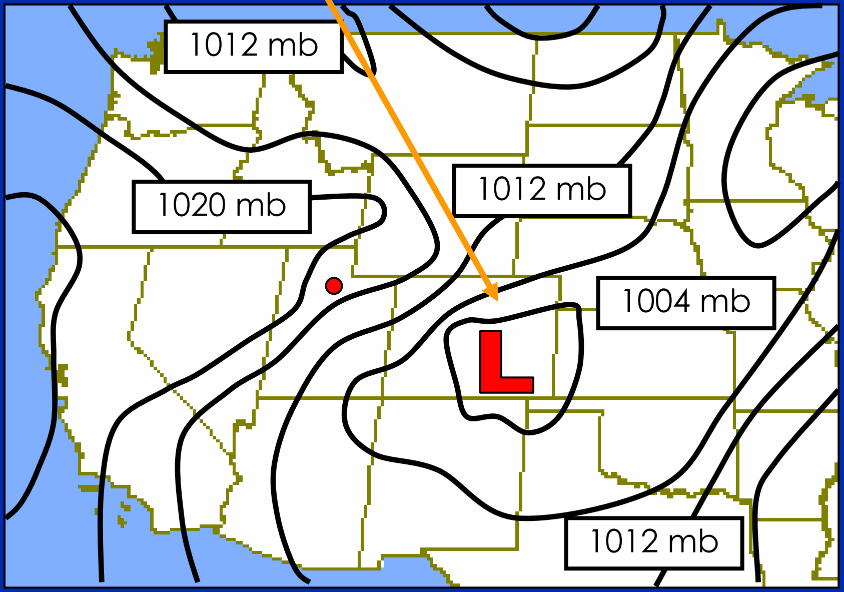
High $PM_{2.5}$ in Salt Lake City, Utah

# Surface Highs and Lows – Relationship to Aloft Pattern (2 of 2)

Trough = Rising = Surface low




500-mb heights on the afternoon of January 22, 2002 (00Z Jan 23)




Surface pressure on the afternoon of January 22, 2002 (00Z Jan 23)

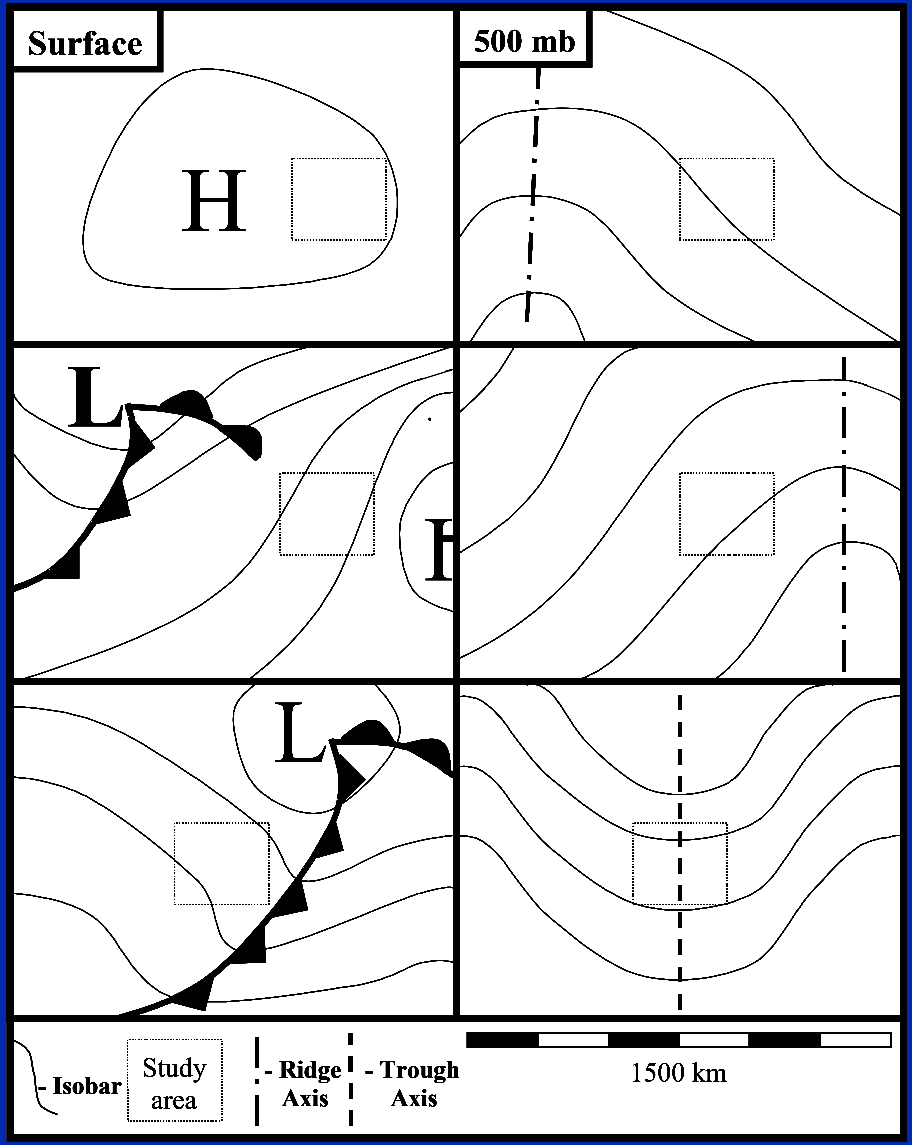
## Low $PM_{2.5}$ in Salt Lake City, Utah

# Life-cycle of Aloft and Surface Patterns

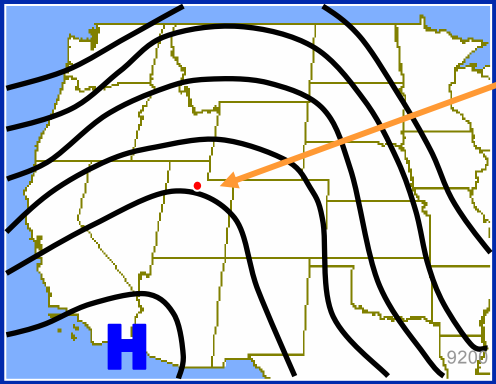
Surface High
Approaching Ridge

Backside Surface High
Warm Front
Approaching Trough

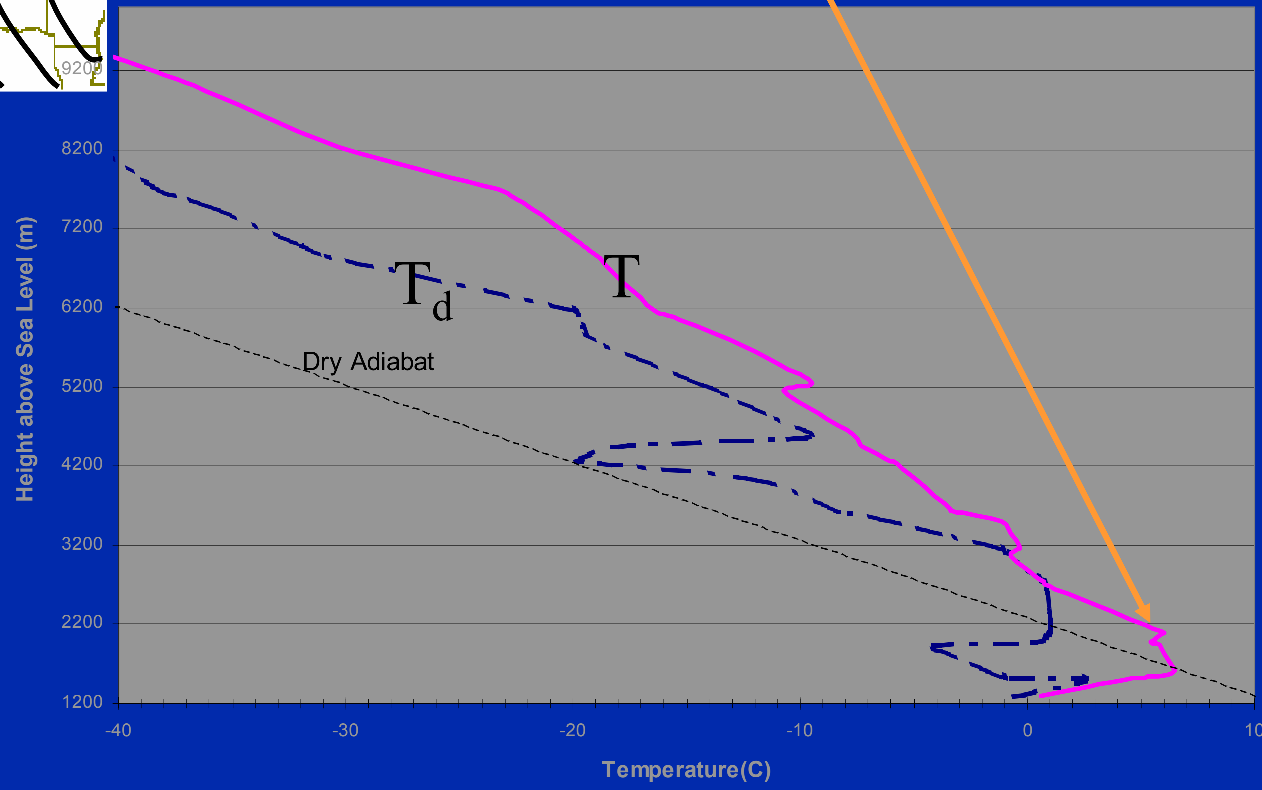
Surface Low
Cold Front
Trough



# Ridges and Temperature Soundings

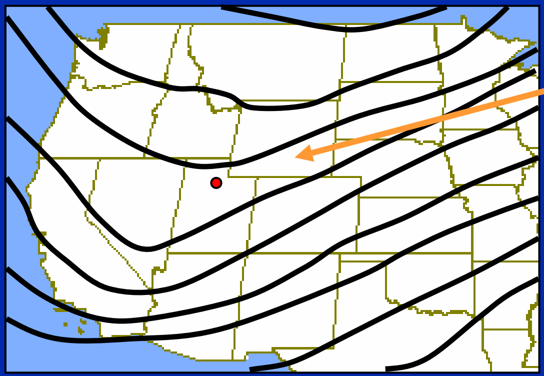



Ridge =
Sinking =
Strong Inversion =
Poor Air Quality

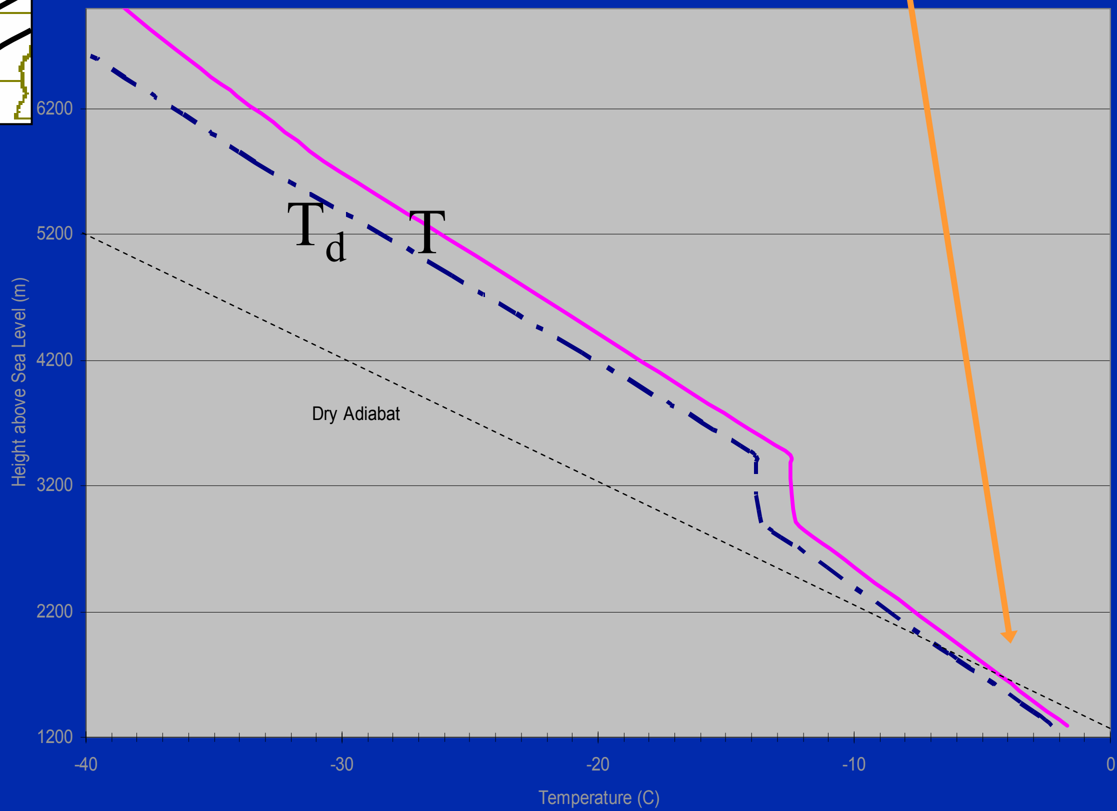



Salt Lake City, Utah, temperature and dew point temperature sounding on January 7, 2002, at 0500 MST

# Troughs and Temperature Soundings



Trough =
Rising =
No Inversion =
Good Air Quality

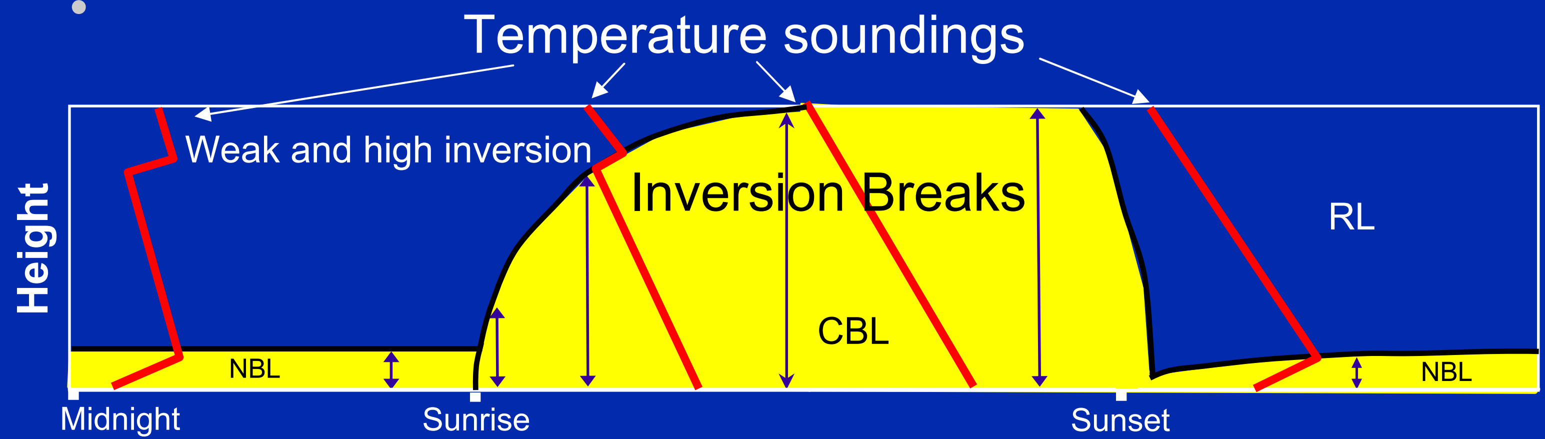



Salt Lake City, Utah, temperature and dew point temperature sounding on January 22, 2002, at 0500 MST

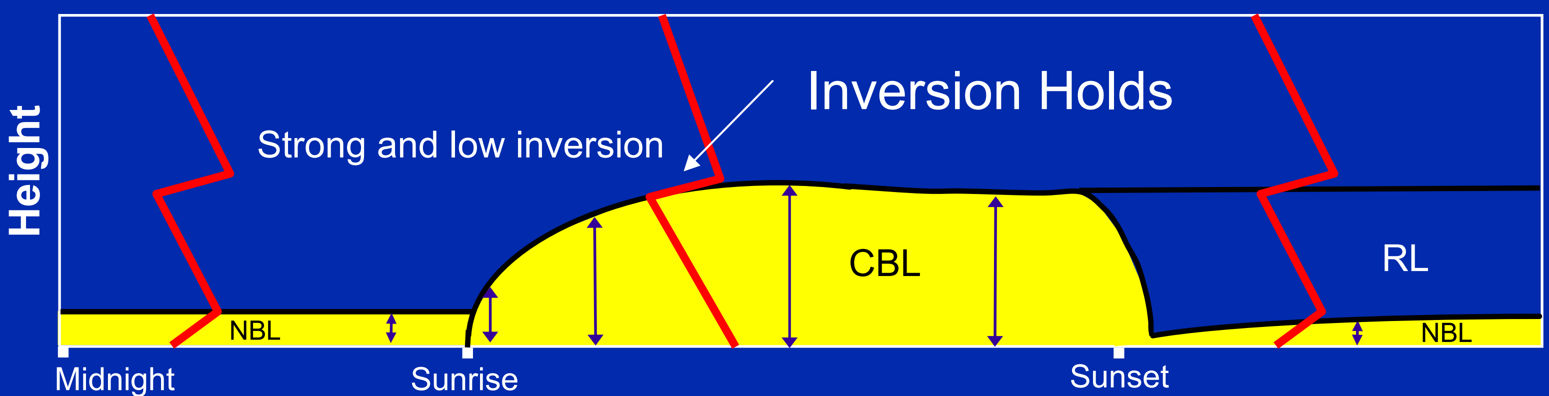
# Inversions

- Subsidence
  - Created by sinking air associated with ridges
  - Can limit daytime mixing depth and plays important role in daytime pollutant concentrations
- Nocturnal
  - Created by cooling ground at night
  - Strongest with clear skies, light winds, and long nights
  - Can trap emissions, released during the overnight hours, close to the ground
- Advection
  - Created when warm air aloft moves over cooler air below
  - Can occur ahead of an approaching cold front
  - Can cause poor air quality, despite the lack of an aloft ridge

# Inversions and Mixing




Pollutants mix into a large volume resulting in low pollution levels




Pollutants mix into a smaller volume resulting in high pollution levels

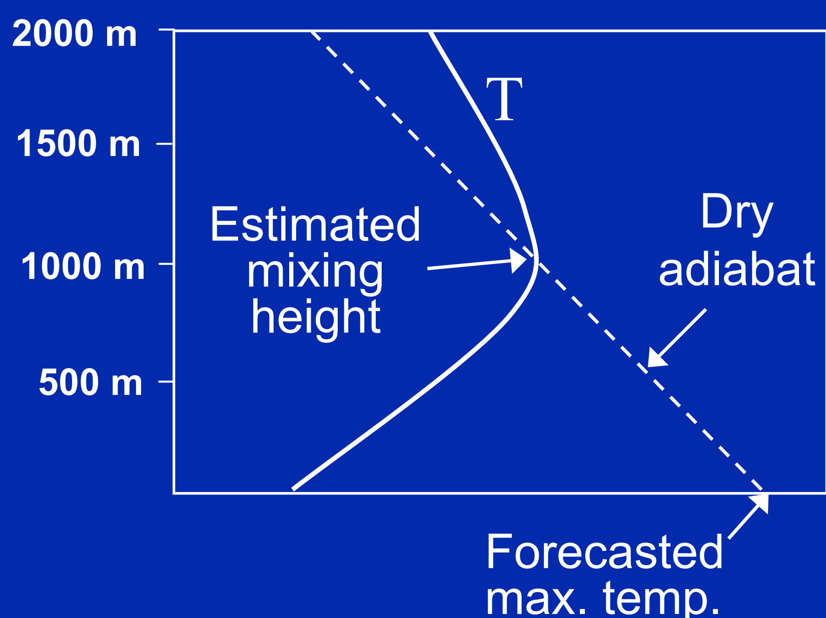
RL = Residual Layer
CBL = Convective Boundary Layer
NBL = Nocturnal Boundary Layer

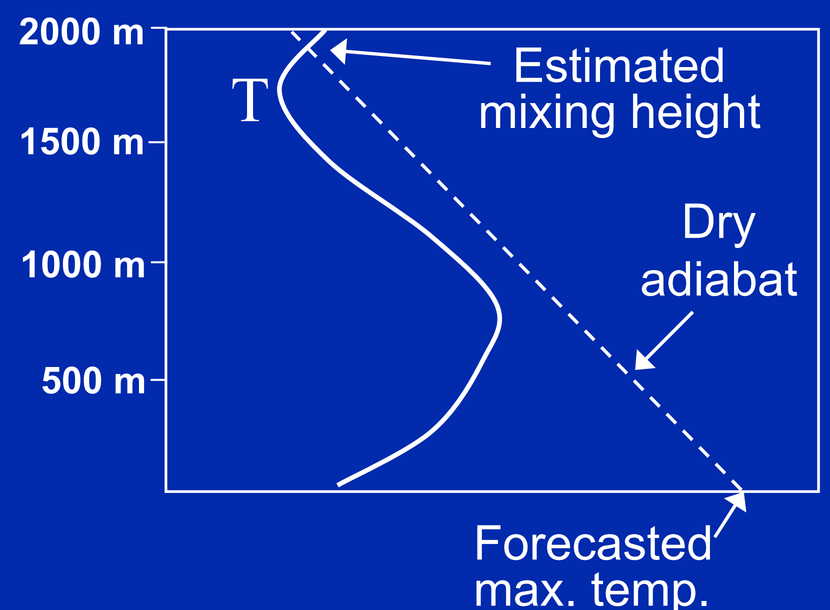
**= Surface-based mixing depth**

**= Surface-based vertical mixing**

# Mixing and Temperature Soundings – Estimating Mixing Height

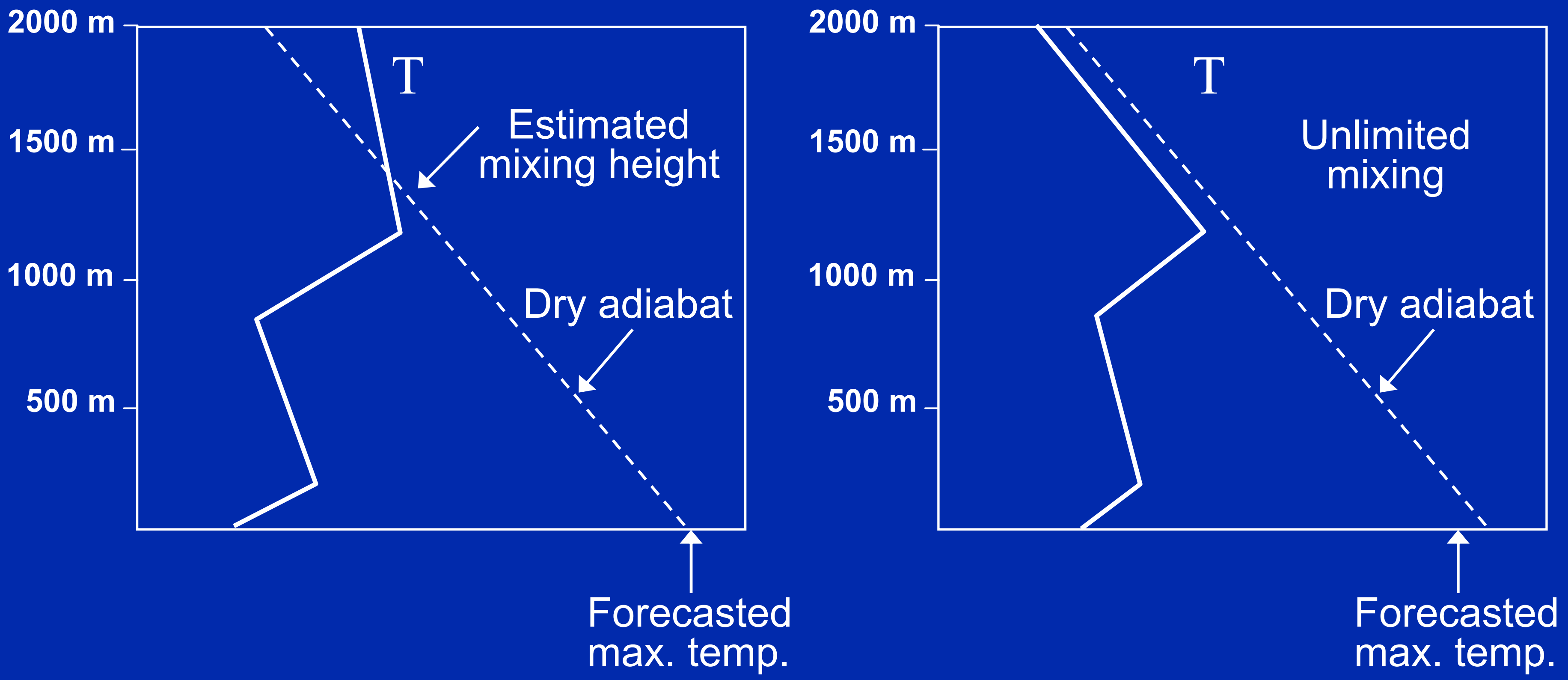
- <u>Holzworth Method</u> – Starting at the forecasted maximum temperature, follow the dry adiabat (dashed line) until it crosses the morning sounding. This is the estimated peak mixing height for the day.
- The dry adiabatic rate is the rate at which an unsaturated air parcel cools as it rises. It is defined as -9.8ºC per km.
- Uncertainty in mixing height estimates can be caused by changes in aloft temperatures or errors in predicted maximum temperatures.



# Stability – Beyond Inversions

- A measure of the ability of an air parcel to rise
- Inversions create stable conditions
- Stable conditions in a temperature profile can exist without an inversion



# Clouds and Precipitation (1 of 2)

- Clouds form when the air becomes saturated
  - Adding water vapor
  - Cooling air
- Many processes add water vapor or cool air
  - Rising motion
    - Trough
    - Daytime heating
    - Cold front undercutting warm air (or vice versa)
    - Orographic
  - Air in contact with cooler surface
  - Air moving over water
  - Others

# Clouds and Precipitation (2 of 2)

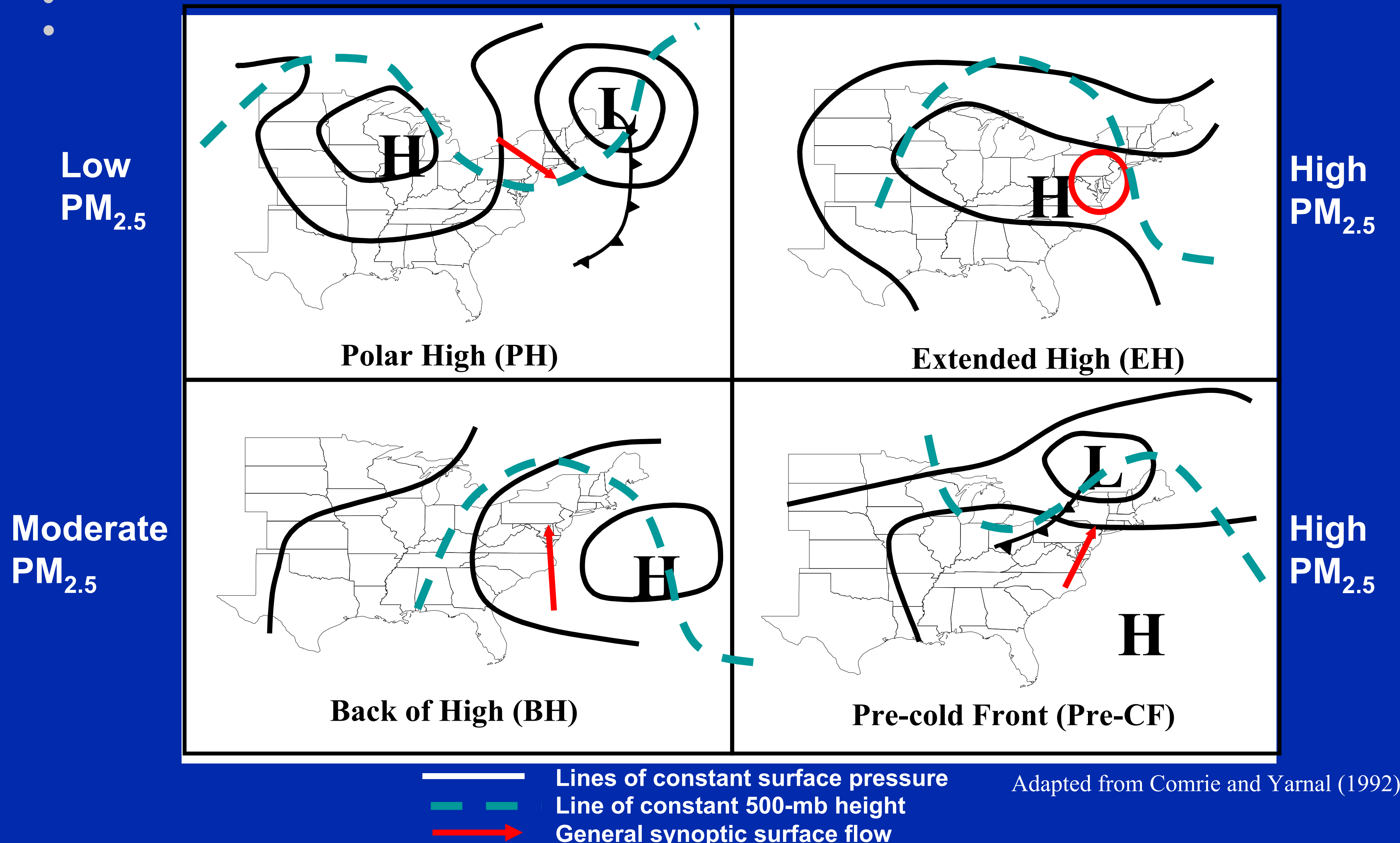
- Clouds and fog can increase the conversion of sulfur dioxide to sulfate from 1% per hour to 50% per hour
  - Important in the East where one-half of $PM_{2.5}$ is sulfate
- Clouds reduce ozone photochemistry
- Precipitation removes $PM_{10}$ but has little direct impact on $PM_{2.5}$
- Convective clouds can vent pollution from the boundary layer under stable conditions
- Inhibits heating and ability to break inversion (mid and high clouds)

# Winds

## Horizontal dispersion and transport

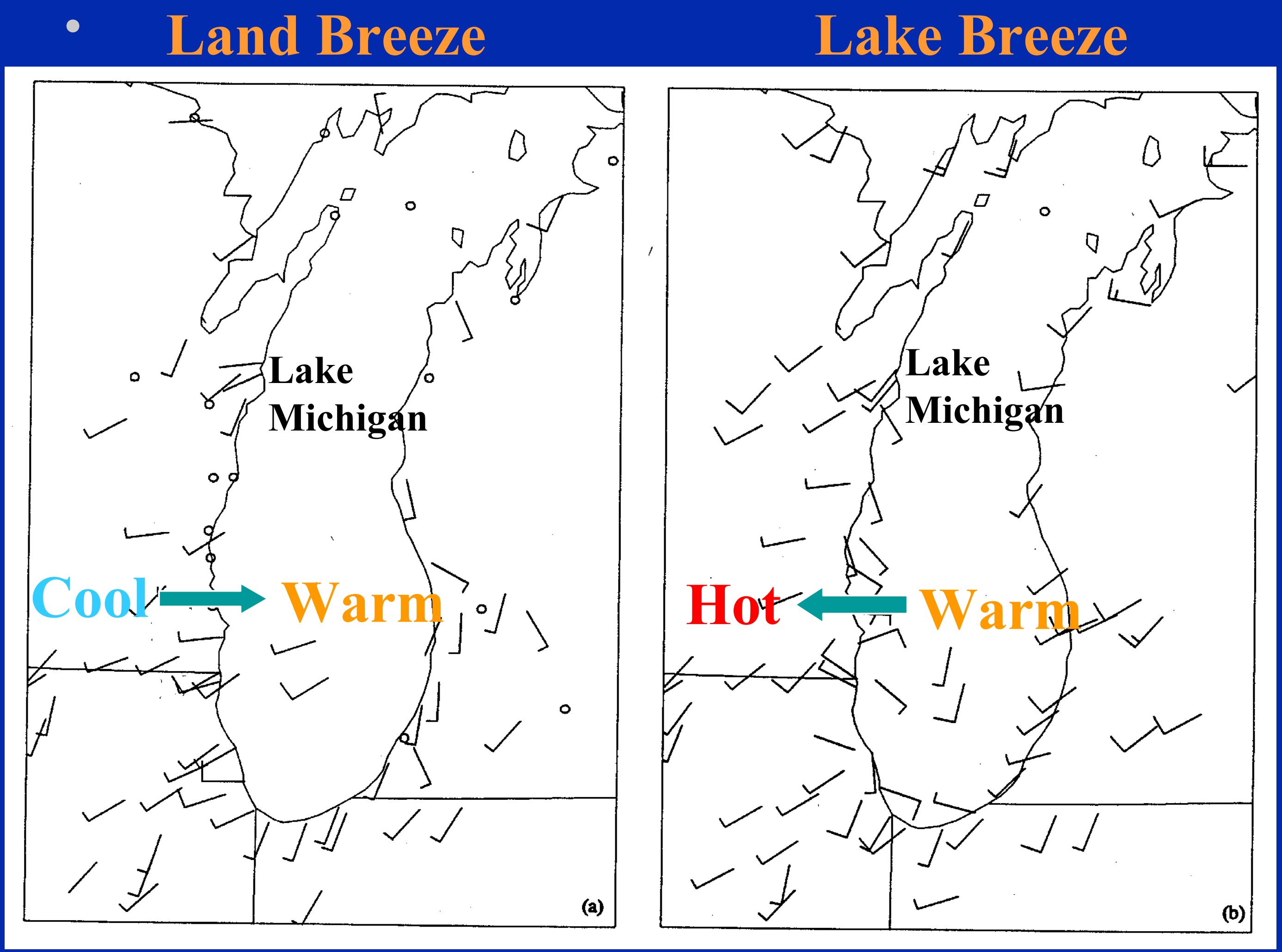
- Synoptic scale
  - Winds are driven by large high- and low-pressure systems
- Meso- and local-scale
  - Land/sea or lake breeze
  - Mountain/valley
  - Terrain forced
  - Diurnal cycles
  - Foster stagnation and recirculation
  - Local flows are often difficult for weather models to predict but can be predicted by forecasters with knowledge of the area
- Surface vs. boundary layer
  - Transport at different levels
  - Mixing during the day

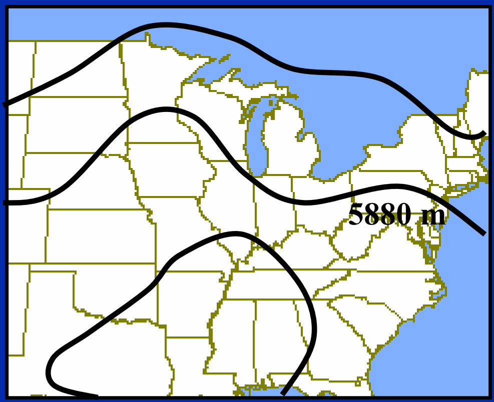
# Winds – $PM_{2.5}$ Variation with Synoptic Pattern



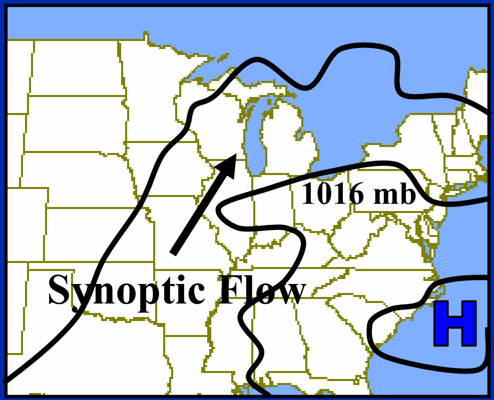

Adapted from Comrie and Yarnal (1992)

# Winds – Mesoscale (1 of 2)



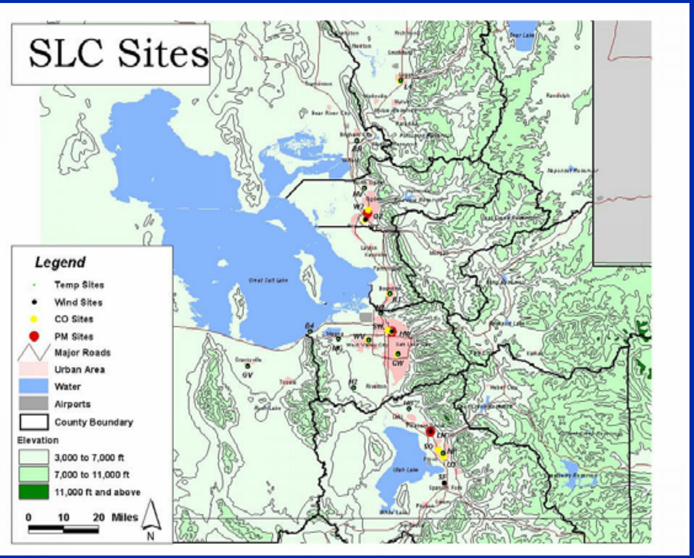

500-mb heights on July 18, 1991

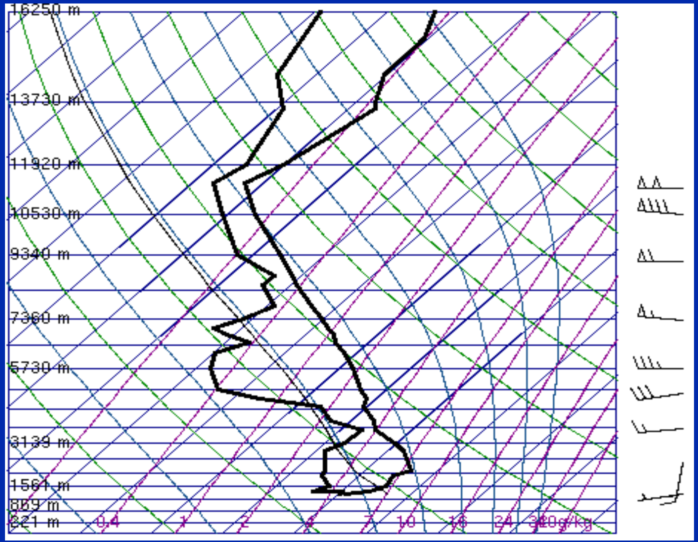


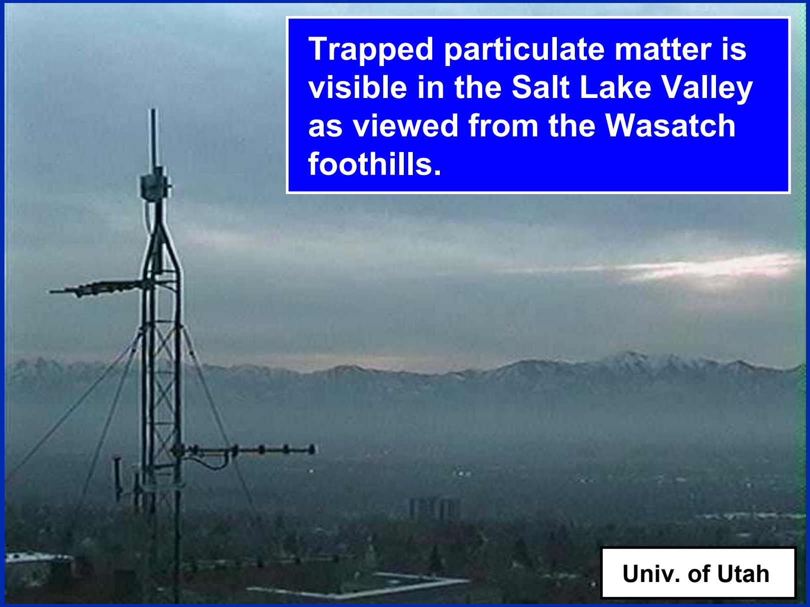

Surface pattern on July 18, 1991

Surface winds on July 18, 1991, at (a) 0600 CDT and (b) 1500 CDT. Peak ozone concentrations on this day were about 170 ppb. (Dye et al., 1995)

# Winds – Mesoscale (2 of 2)

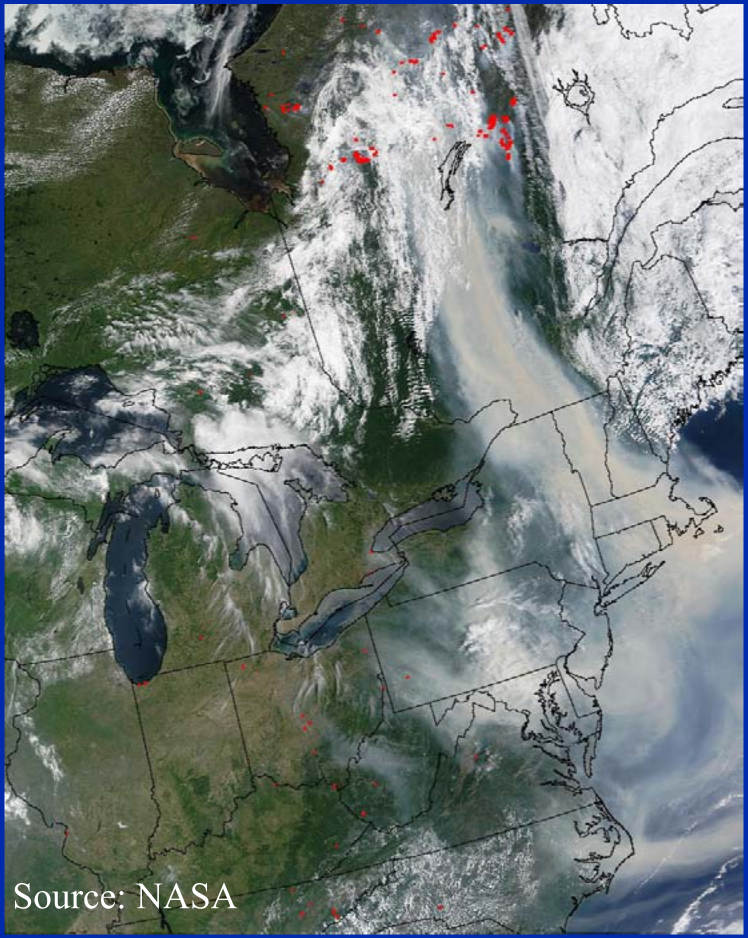


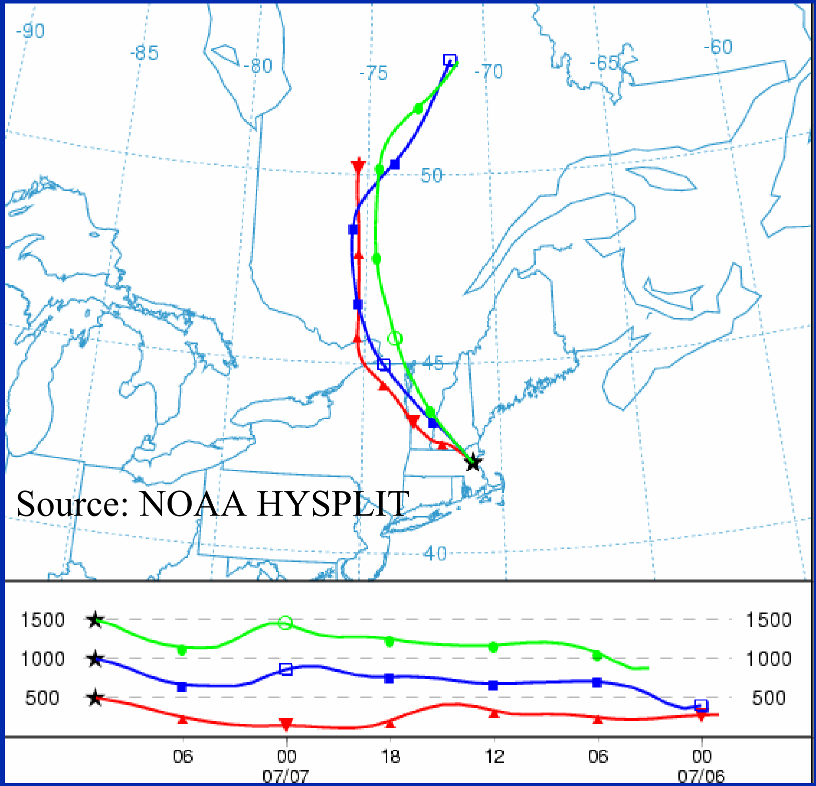




With a strong inversion and the surrounding mountains, surface winds are decoupled from the aloft winds. The strong inversion and light surface winds allow for high $PM_{2.5}$ concentrations.

# Transport



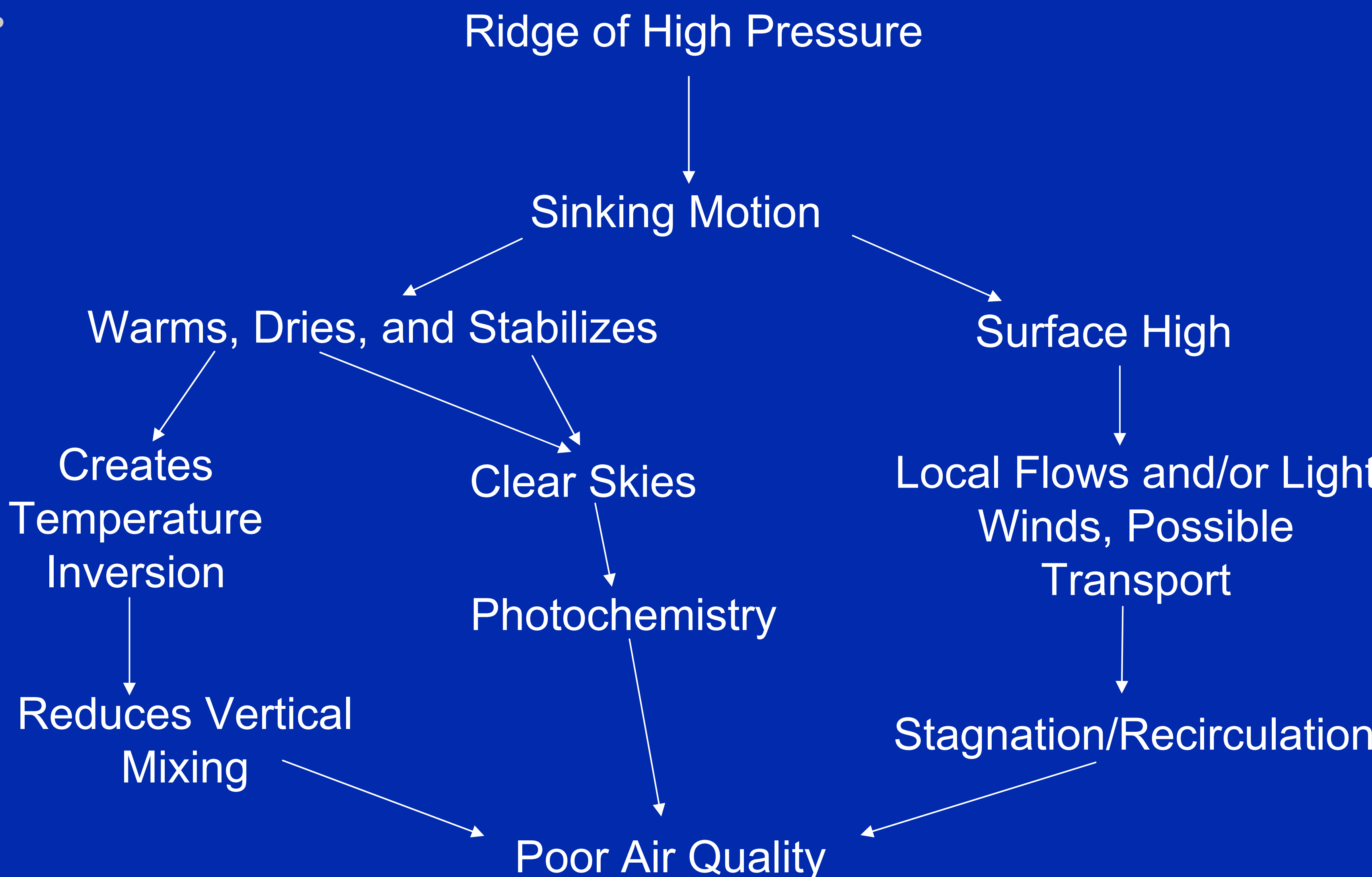

**The 24-hr average $PM_{2.5}$ concentration in Boston on 7/7/02 was 62.7 µg/$m^3$**



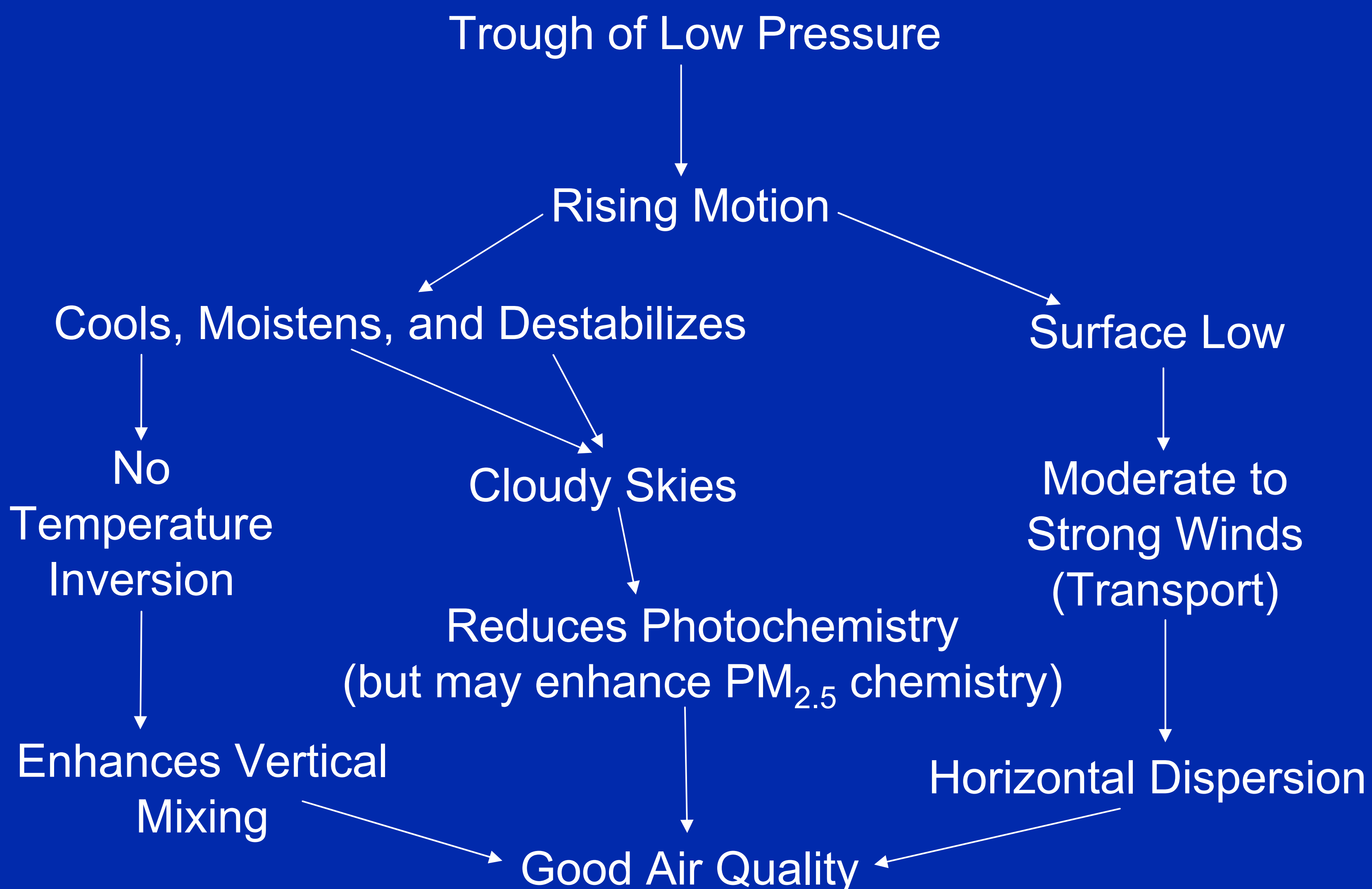

2-km satellite image from 1235 EST on 7/7/02

Backward trajectory ending at 0600 EST on 7/7/02

# Summary – Meteorology Associated with Poor AQ



# Summary – Meteorology Associated with Good AQ



# Summary – Importance of Variables

| Variable | PM | Ozone | CO |
|---|---|---|---|
| Inversion Strength | High | High | High |
| Surface Temp. | Medium | High | High |
| Humidity | High | Medium | Low |
| Aloft Pattern | Medium | High | Medium |
| Cloud Cover | Low | High | Medium |
| Wind Speed | High | Medium | High |

Importance of each variable varies by region and season

# Summary

Processes that influence air quality

- Sunlight
- Horizontal dispersion
- Vertical mixing
- Transport
- Clouds and Precipitation

- Next step – Meteorological Products and Examples
- Questions