（1）静力平衡大气中的气压变化: p坐标

上节课回顾

$$\frac{\partial z(p_b)}{\partial t} = -\frac{1}{\mathrm{g}}\int_{p_t}^{p_b} \mathrm{R}\left(-\vec{\mathbf{v}}\cdot\nabla_p T + \omega\sigma + \frac{q}{\mathrm{c_p}}\right) d\ln p + \frac{\partial z(p_t)}{\partial t}$$

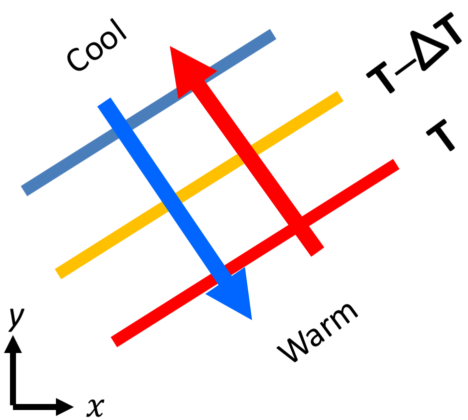
温度平流　　绝热过程　　非绝热过程

p_t很小 时，约为0

地面

< 0，减低　　暖平流

> 0，增压　　冷平流



（3）动力和浮力扰动气压

上节课回顾

$$\nabla^2 p' = -\rho_0\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right] - 2\rho_0\left[\frac{\partial v}{\partial x}\frac{\partial u}{\partial y} + \frac{\partial w}{\partial x}\frac{\partial u}{\partial z} + \frac{\partial w}{\partial y}\frac{\partial v}{\partial z}\right] + \rho_0\frac{\partial B}{\partial z} + \mathrm{f}\rho_0\zeta$$

矢量形式 $\nabla^2 p' = -\rho_0 \nabla\cdot(\vec{\boldsymbol{v}}\cdot\nabla\vec{\boldsymbol{v}}) + \rho_0\frac{\partial B}{\partial z} - \rho_0 \mathrm{f}\,\nabla\cdot(\vec{\mathrm{k}}\times\vec{\boldsymbol{v}})$

$\nabla^2 p_{\mathrm{D}}'$	$\nabla^2 p_{\mathrm{B}}'$	$\nabla^2 p_{\mathrm{G}}'$
动力	浮力	地转

几点说明：

（1）适用于anelastic或Boussinesq近似；

（2）可以基于风场和浮力场计算气压；

（3）全可压缩模式中，分析不同的影响因子或者背景与风暴尺度各自的影响时，一般仅计算其中两项，用余差求最后项。

（3）动力和浮力扰动气压

上节课回顾

3）动力部分

$$\nabla^2 p_D' = -\rho_0\left[\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial w}{\partial z}\right)^2\right]-2\rho_0\left[\frac{\partial v}{\partial x}\frac{\partial u}{\partial y}+\frac{\partial w}{\partial x}\frac{\partial u}{\partial z}+\frac{\partial w}{\partial y}\frac{\partial v}{\partial z}\right]$$

三维涡度（spin） $\vec{\omega}=\left[\frac{\partial w}{\partial y}-\frac{\partial v}{\partial z},\frac{\partial u}{\partial z}-\frac{\partial w}{\partial x},\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}\right]$

变形算子（splat） $e_{ij}^2=\frac{1}{4}\sum_{i=1}^{3}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)^2$

$$u_1=u;u_2=v;u_3=w \quad x_1=x;x_2=y;x_3=z$$

$$\nabla^2 p_D' = \rho_0\left[\frac{1}{2}|\vec{\omega}|^2-e_{ij}^2\right]$$

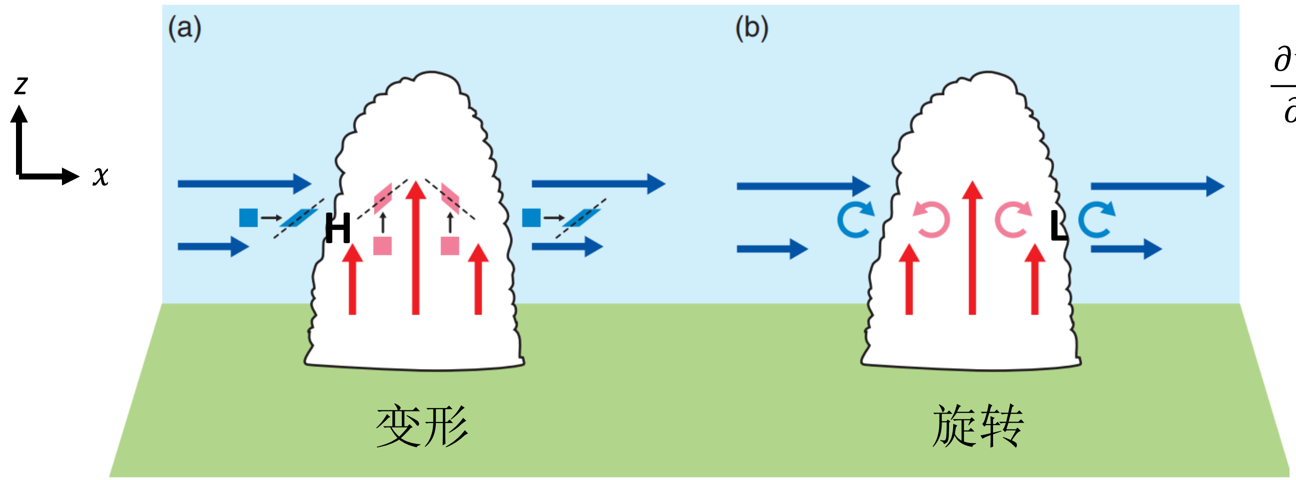
$\Rightarrow$ $p_D' \propto e_{ij}^2-\frac{1}{2}|\vec{\omega}|^2$

（5）线性和非线性扰动气压

上节课回顾

线性项 $\frac{\partial w'}{\partial x}\frac{\partial \bar{u}}{\partial z}+\frac{\partial w'}{\partial y}\frac{\partial \bar{v}}{\partial z}$

背景和扰动对变形和旋转的作用在切变上下游的共同作用可用来解释切变背景下指向切变下游方向的水平气压梯度力。

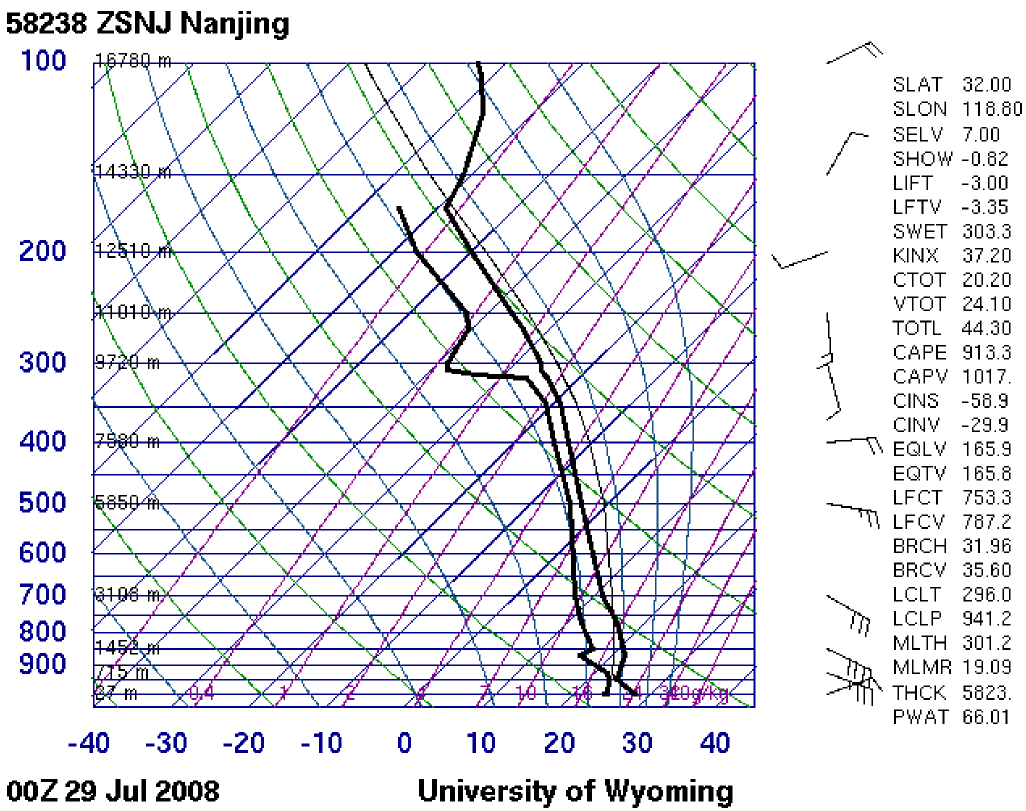


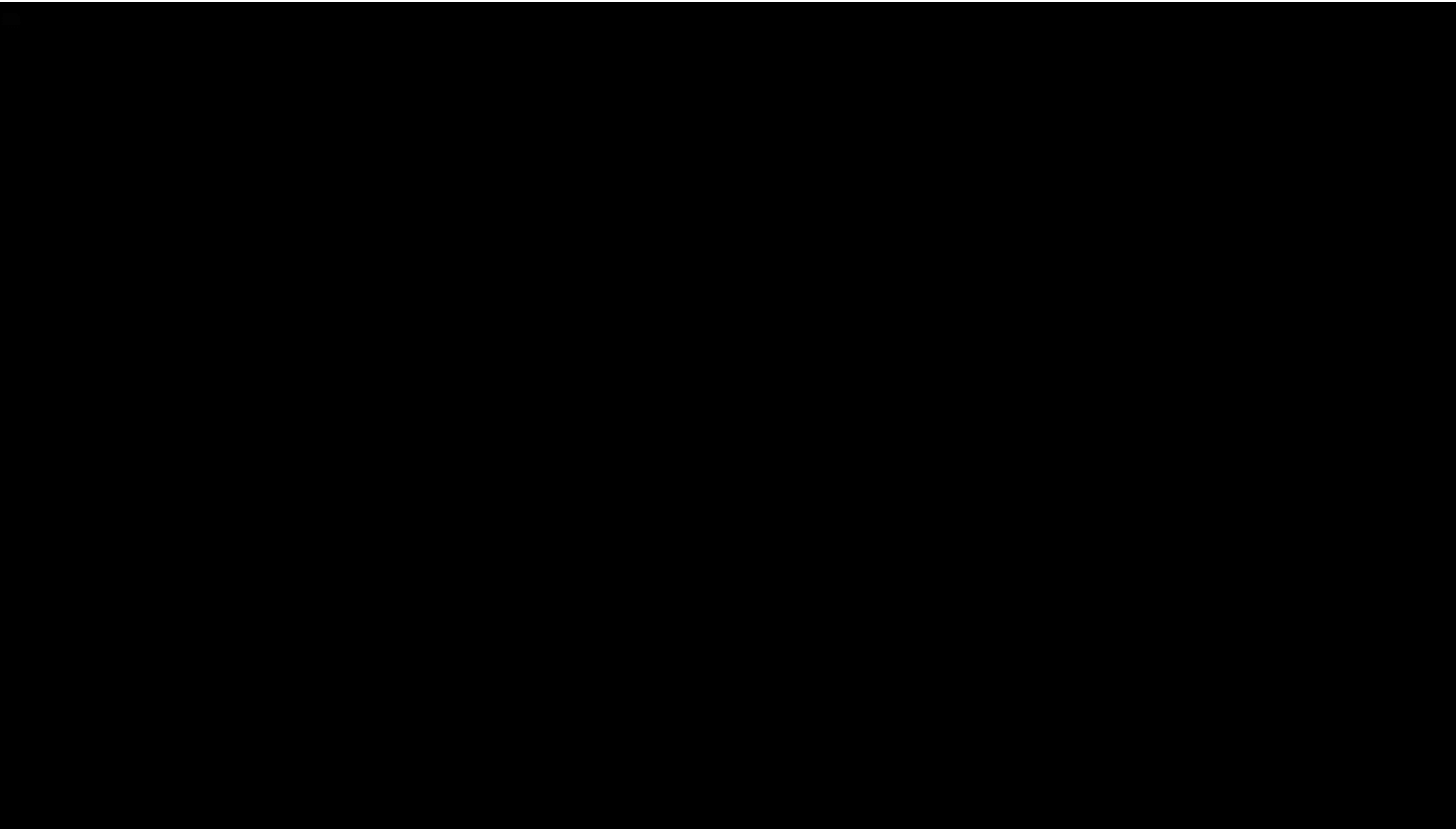
$\frac{\partial w'}{\partial x}\frac{\partial \bar{u}}{\partial z}$

1.4 基本工具

- Skew-T
- Hodograph
- Radar analysis

Skew-T-log P Diagram





2019年8月上海台风所

Skew-T

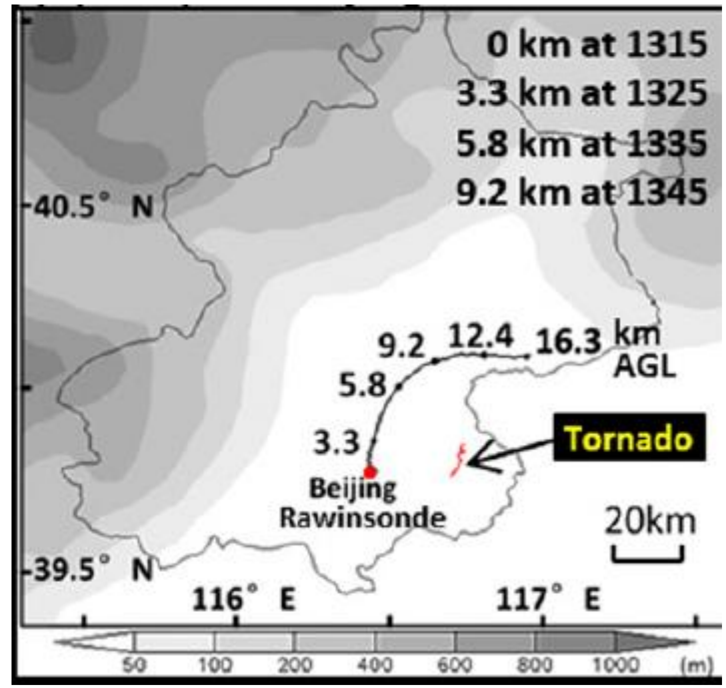
- 一种非常重要的天气分析预报工具，尤其是用于**强对流天气的潜势预报**。
- 通过对气压，温度，湿度的一定表示方法实现**大气能量变换**的可视化。
- 基于探空温湿风垂直廓线和气块法分析，**直接得到大气的各种湿度、温度、和风场参数**，用于大气稳定度和风垂直切变分析。

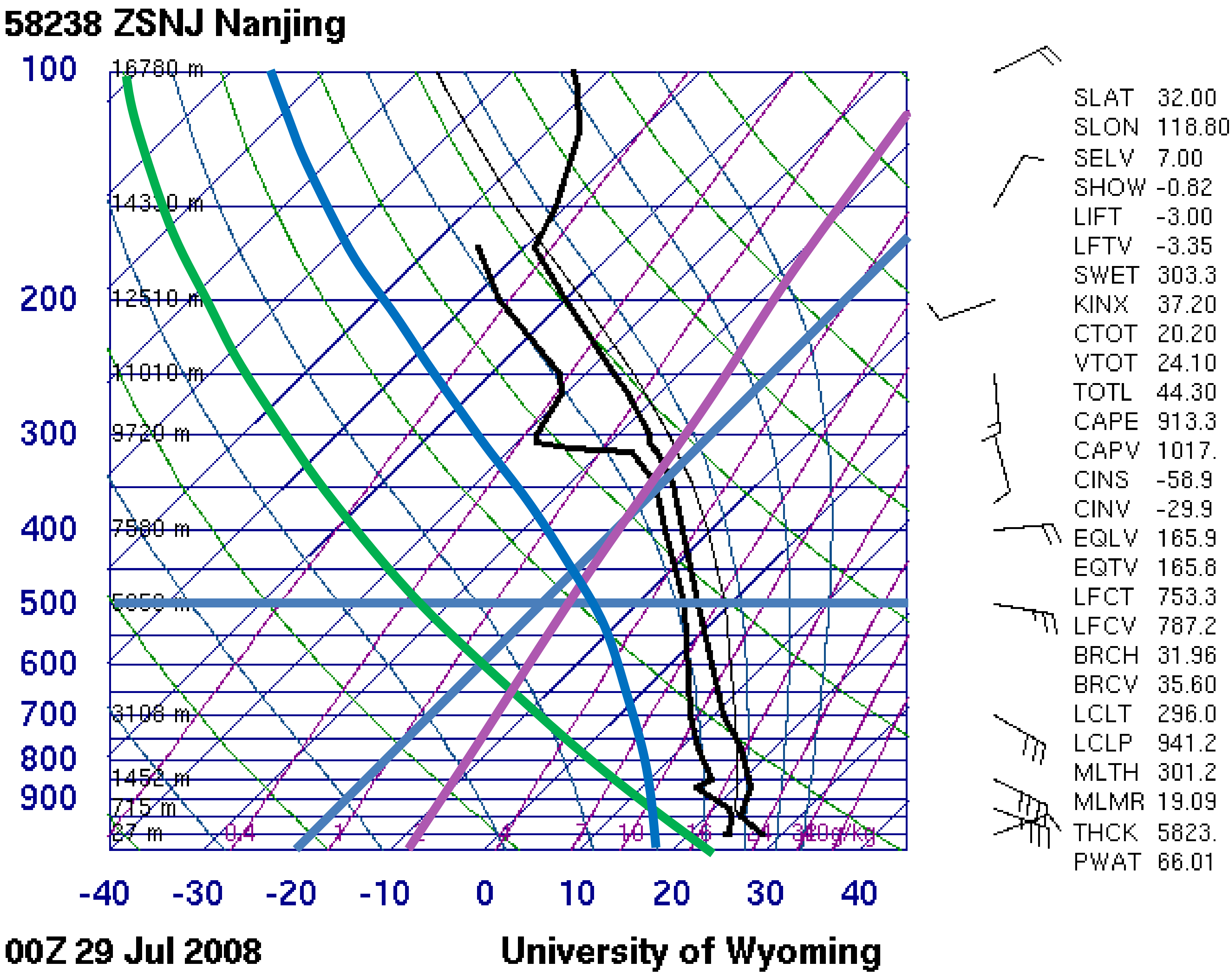
Parcel Theory

- 用途：分析上下移动的气块与周围环境之间的物理量差别，得到**周围环境**的特征
- 气块：一个充分混合的空气微团
- 气块的移动满足如下假定：
  - 气块始终保持与周围环境相同的气压
  - 气块与环境没有物质和能量交换
    - 气块遵循绝热过程
      - 其温度、湿度的变化仅来源于气压变化和凝结潜热
    - 环境不受气块影响
    - 假绝热过程（水汽凝结为水后马上落出气块）
    - 没有卷入过程

探空曲线

- 代表测站周围~200km 范围内的大气特征
- 不是瞬时观测，探空气球升空需要时间
  - 升速5-8m/s, 可到达30km高，历时90-120分钟，
- 不是一个点的观测，气球会漂移
- 12小时一次，对强对流分析太稀




58238 ZSNJ Nanjing
100
200
300
400
500
600
700
800
900
16780 m
14310 m
12510 m
11010 m
9720 m
7580 m
3108 m
1452 m
715 m
27 m
-40
-30
-20
-10
0
10
20
30
40
00Z 29 Jul 2008
University of Wyoming
SLAT 32.00
SLON 118.80
SELV 7.00
SHOW -0.82
LIFT -3.00
LFTV -3.35
SWET 303.3
KINX 37.20
CTOT 20.20
VTOT 24.10
TOTL 44.30
CAPE 913.3
CAPV 1017.
CINS -58.9
CINV -29.9
EQLV 165.9
EQTV 165.8
LFCT 753.3
LFCV 787.2
BRCH 31.96
BRCV 35.60
LCLT 296.0
LCLP 941.2
MLTH 301.2
MLMR 19.09
THCK 5823.
PWAT 66.01

不安全 | weather.uwyo.edu/upperair/sounding.html

University of Wyoming

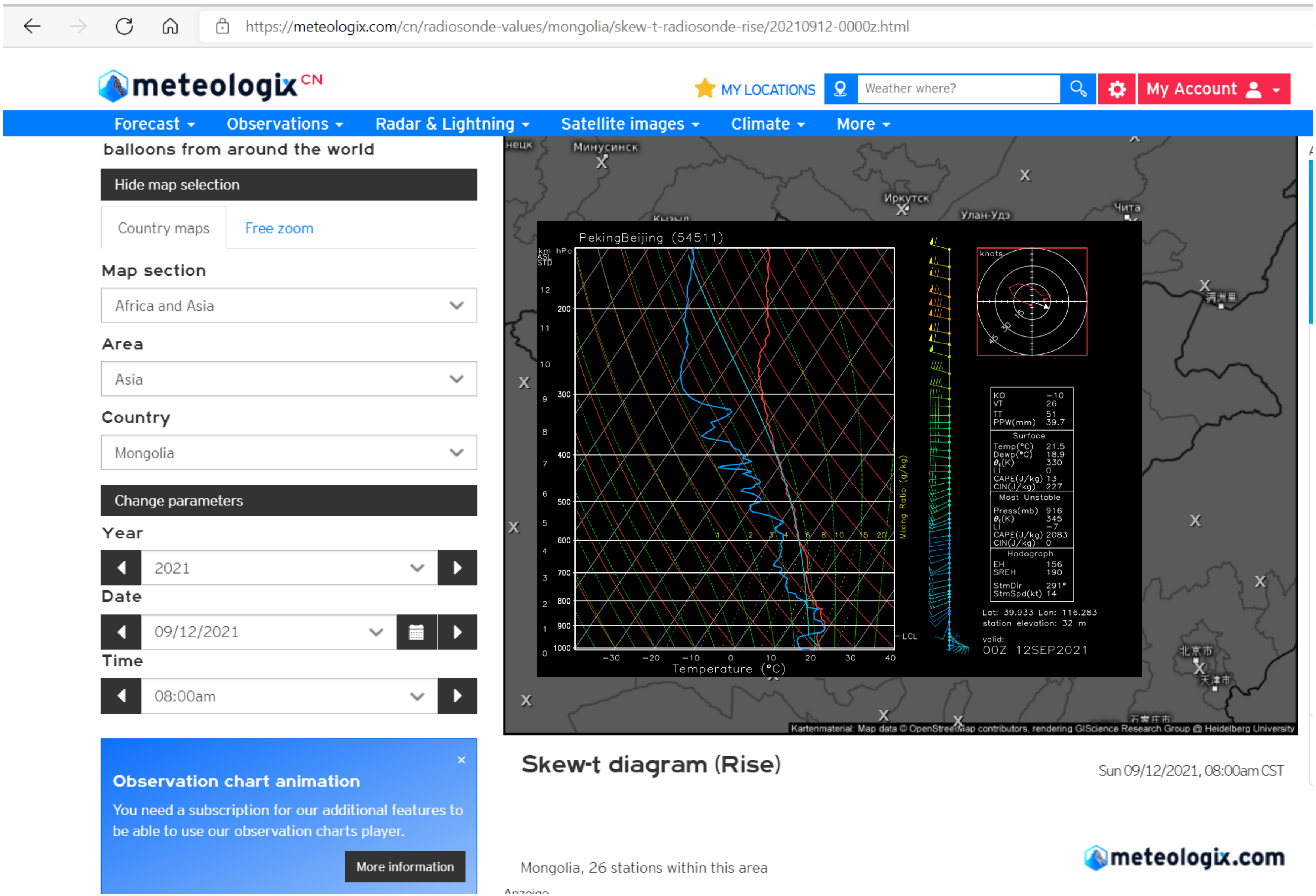
College of Engineering

Department of Atmospheric Science

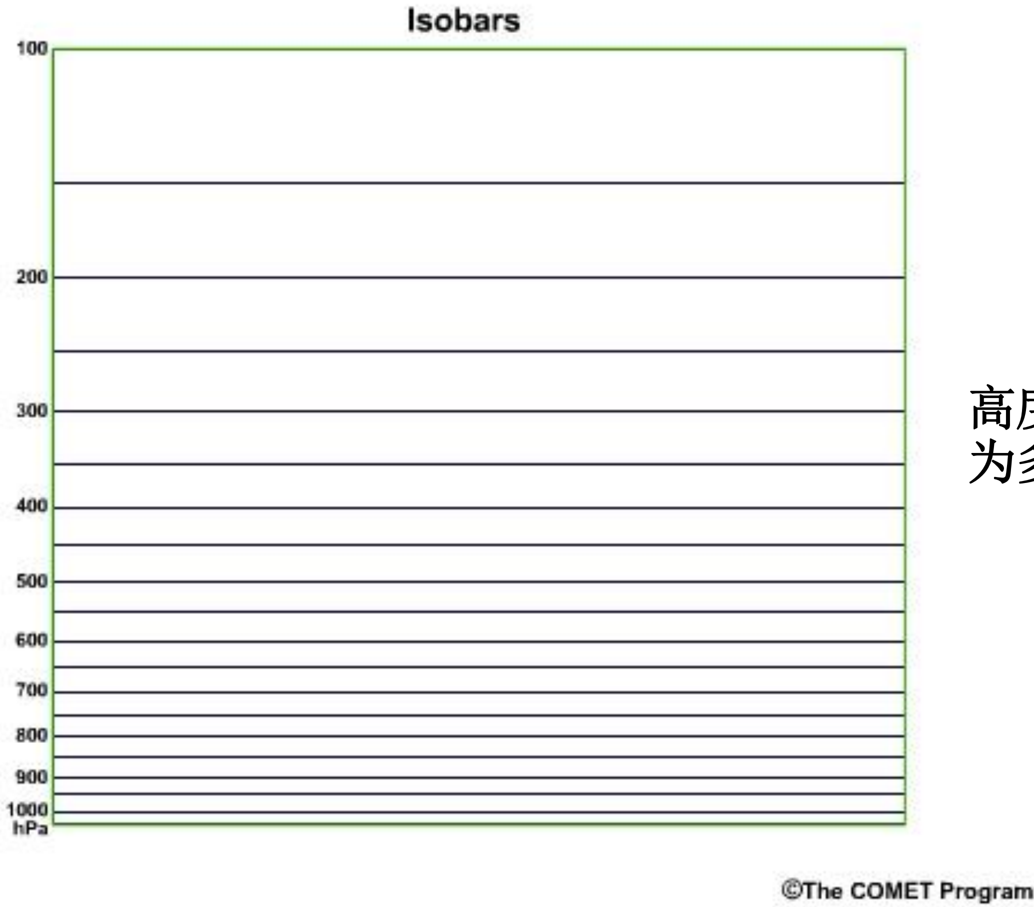
Region	Type of plot	Year	Month	From	To	Station Number
Southeast Asia	Text: List	2021	Sep	21/00Z	21/00Z	72672

Click on the image to request a sounding at that location or enter the station number above.

实时探空图 https://meteologix.com/cn/radiosonde-values



基本线条：等压线



高度约为多少？

1050-100 hPa，间隔50hPa.

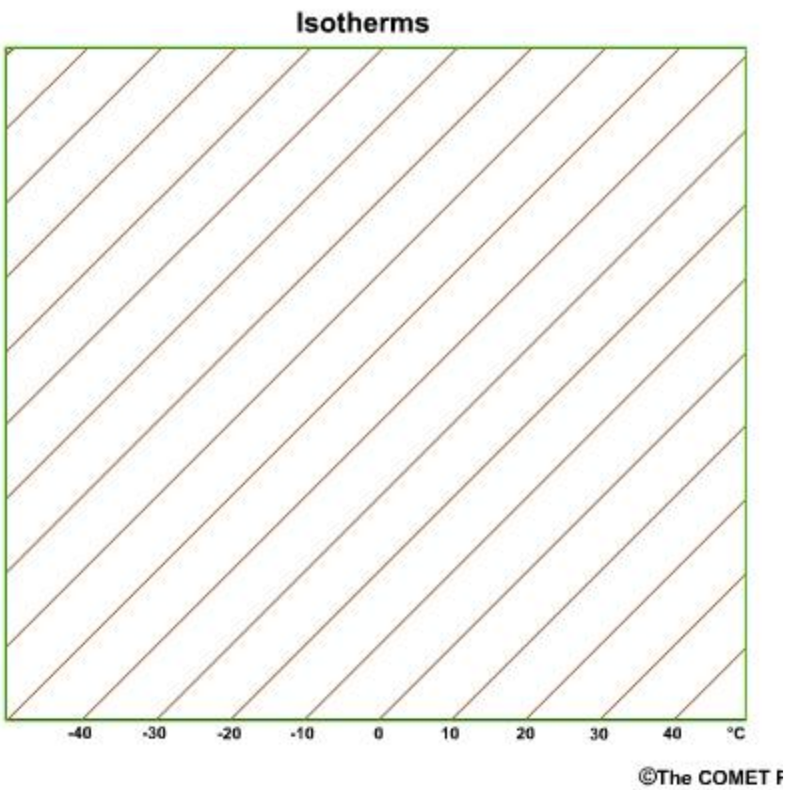
Pressure vs. Height in a Standard Atmosphere		
Pressure (hPa)	Height (m)	Height (ft)
100	16,180	53,083
150	13,608	44,647
200	11,784	38,662
250	10,363	33,999
300	9164	30,065
350	8117	26,631
400	7185	23,574
450	6344	20,812
500	5574	18,289
550	4865	15,962
600	4206	13,801
650	3591	11,780
700	3012	9882
750	2466	8091
800	1949	6394
850	1457	4781
900	988	3243
950	540	1773
1000	111	364

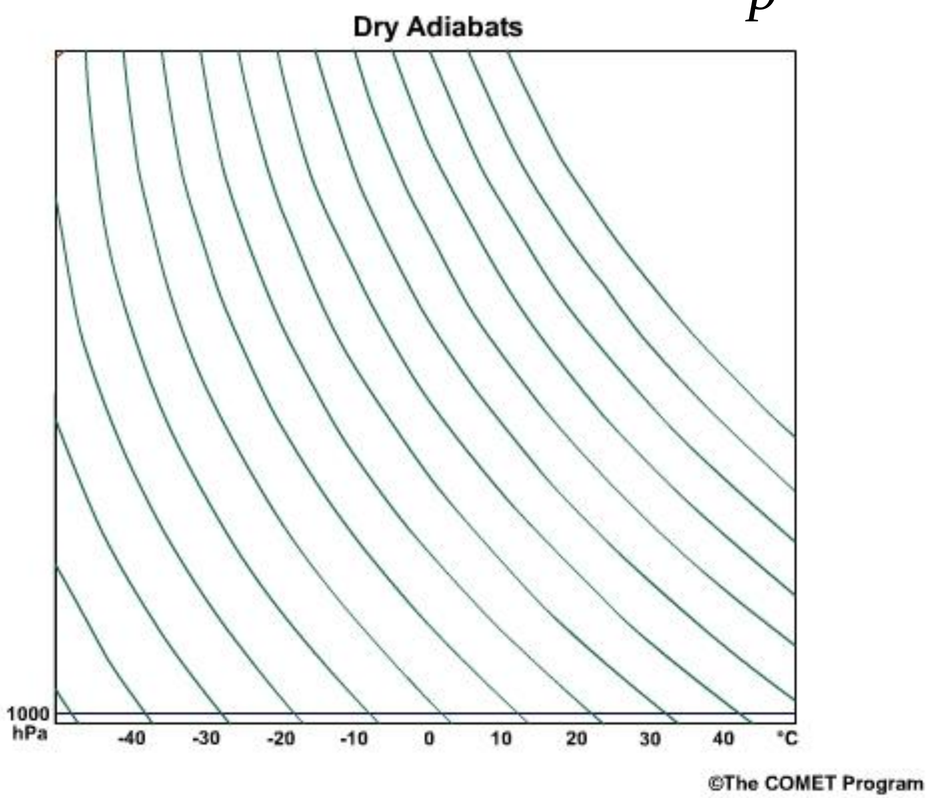
基本线条

等温线:45度角倾斜，-40-40 摄氏度。间隔10度

干绝热线（等位温线）
空气块在绝热上升或下沉过程中的温度变化
-40-40 摄氏度。间隔10度

$$\theta = T\left(\frac{1000}{p}\right)^{\frac{R}{C_p}}$$

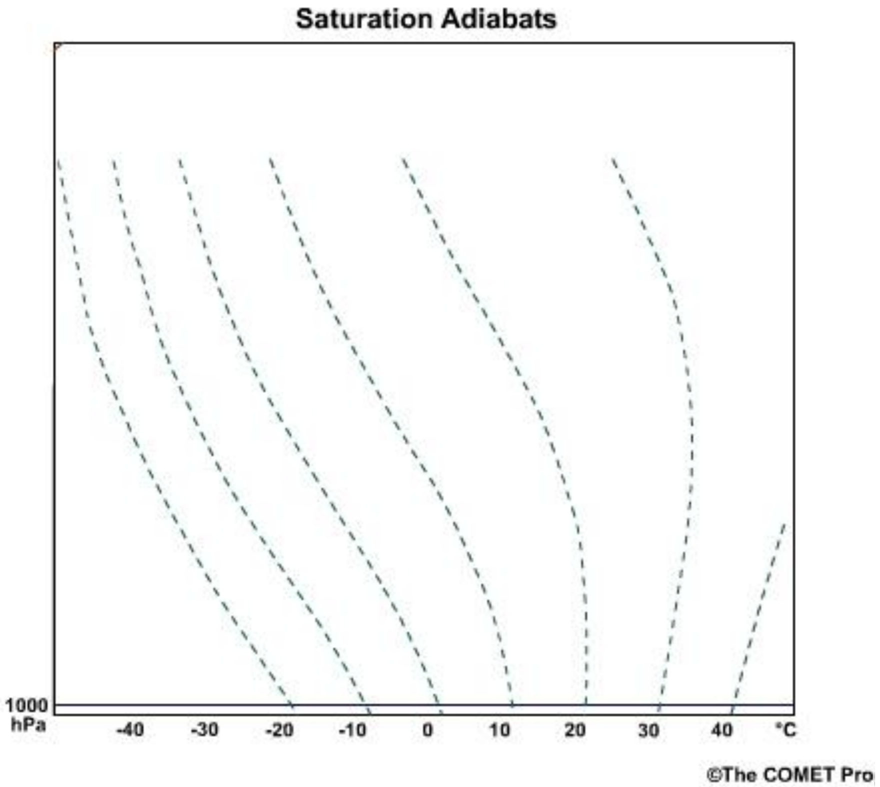


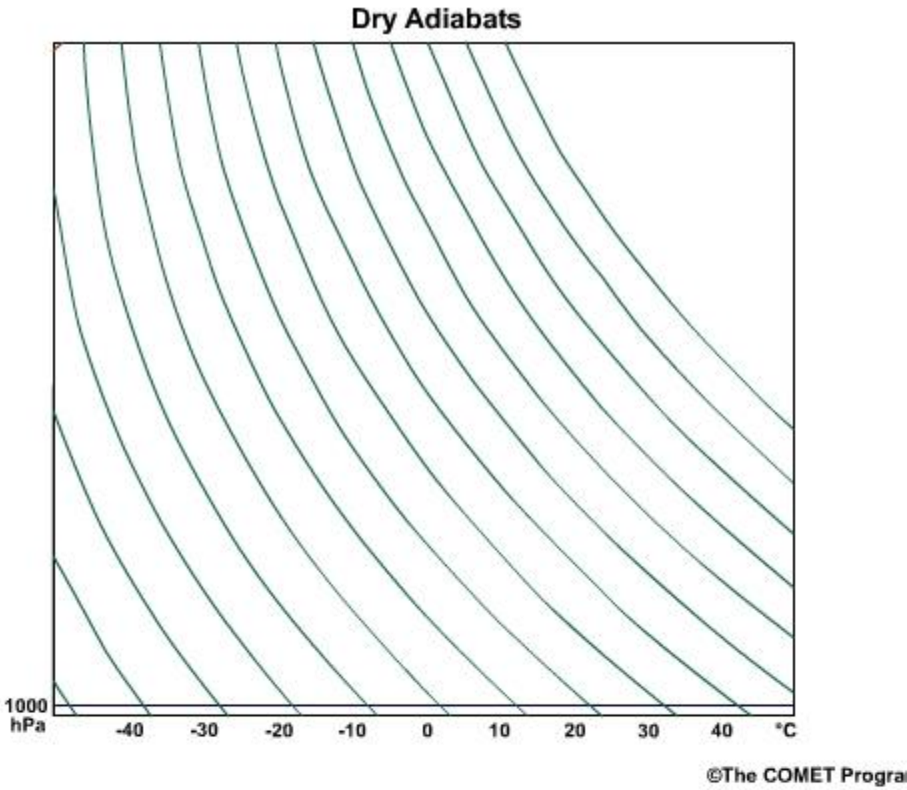


基本线条

湿绝热线（等相当位温线）
饱和空气块在绝热上升或下沉过程中的温度变化
假绝热：水蒸气凝结为水并立刻掉出气块
在低温低压低湿时接近于干绝热线
-40-40 摄氏度。间隔10度

$$\theta_e = \theta(\frac{1+Lq_s}{c_pT_{LCL}})$$





基本线条

等饱和混合比线

0.1-40 g/kg。

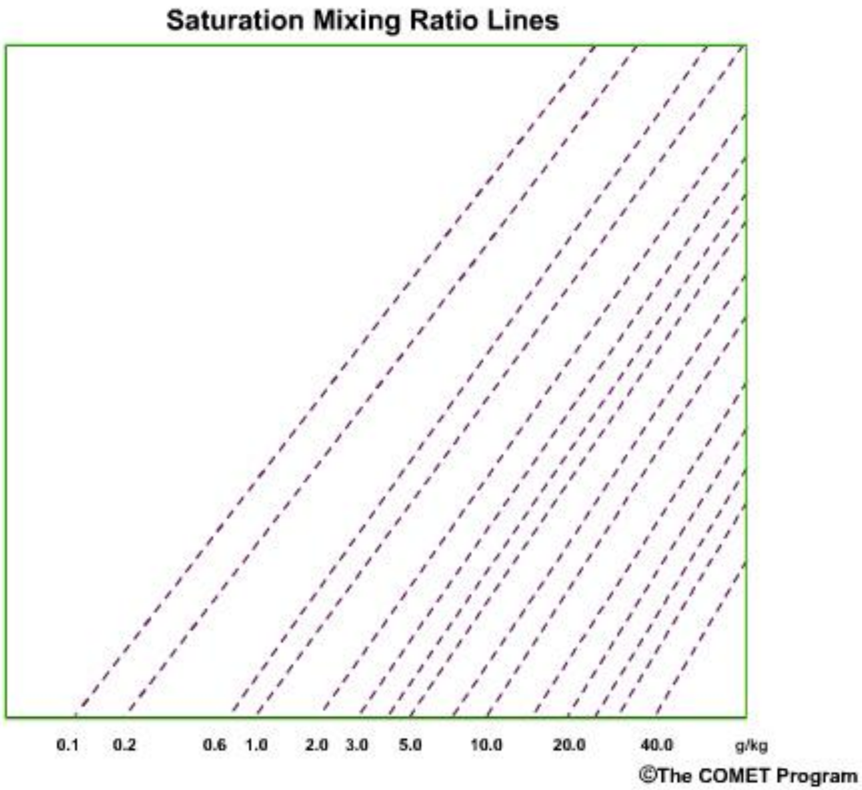
随温度的变化是非线性的

Clausius–Clapeyron relation

$$\frac{\mathrm{d}e_s}{\mathrm{d}T} = \frac{L_v(T)e_s}{R_v T^2},$$

The August–Roche–Magnus formula provides a solution under that approximation

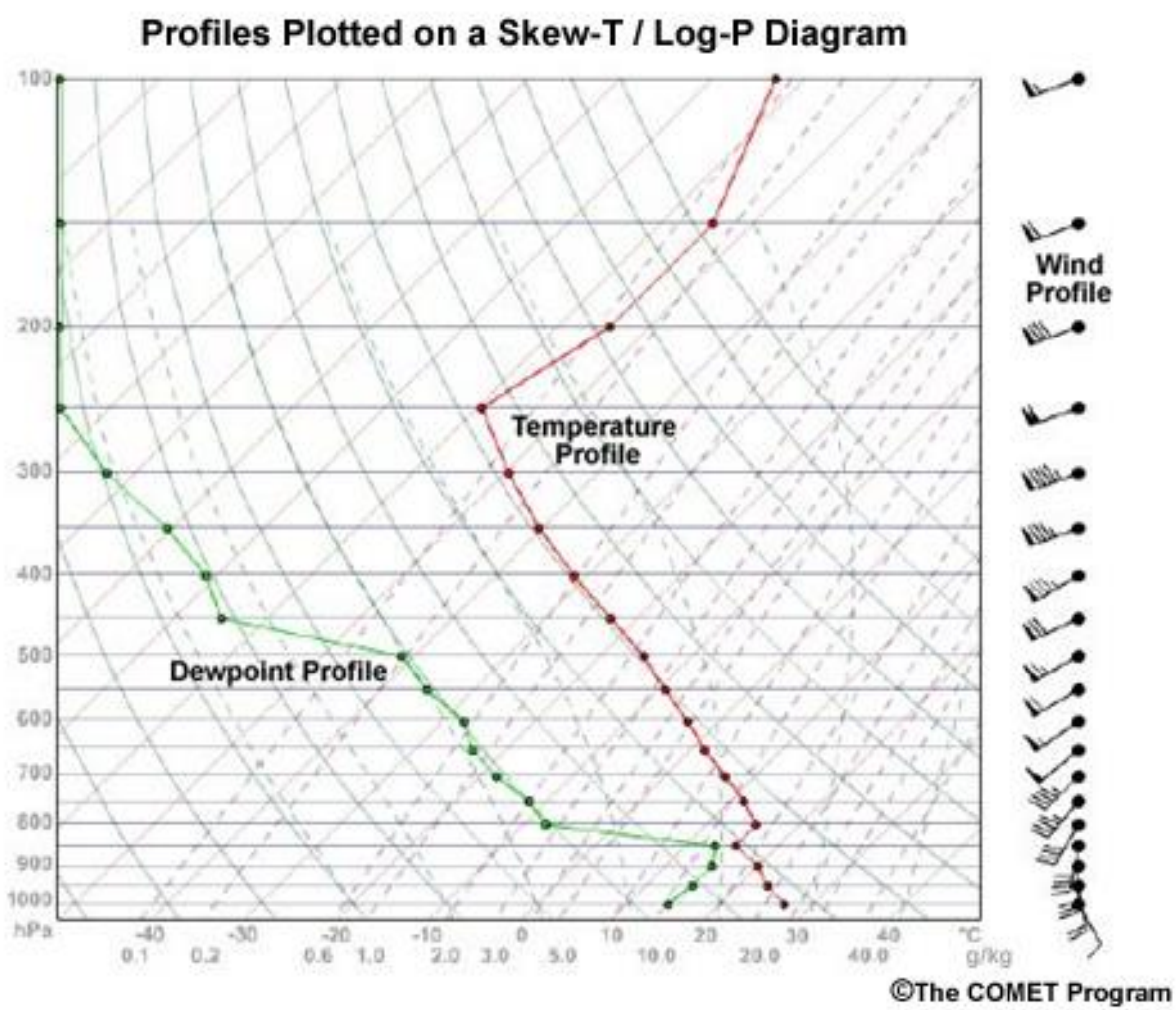
$$e_s(T) = 6.1094 \exp\left(\frac{17.625T}{T + 243.04}\right),$$



基本线条分布的优点

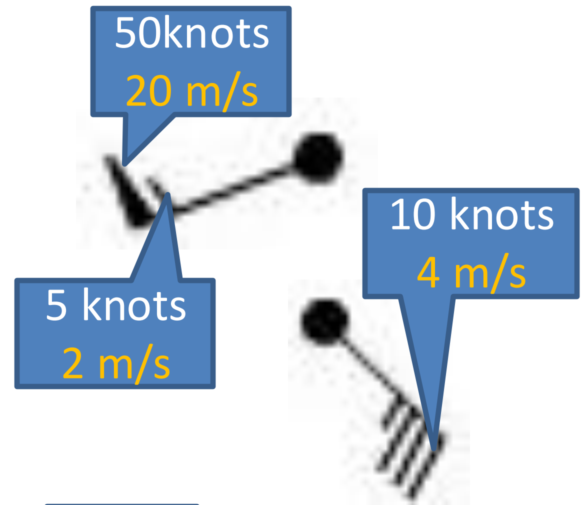
- 图上的面积与能量成比例
- 等温线与干绝热线保持比较大的夹角，更易于看到温度相对于干绝热线的细微变化，更便于分析稳定度。

探空曲线



露点： 气块在保持水汽不变的情况下等压降温到气块饱和时的温度.

风速风向表示



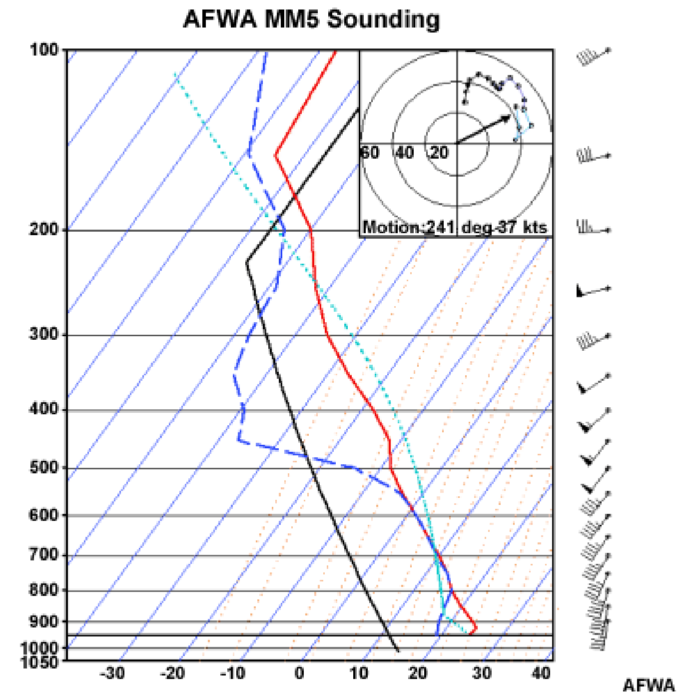
USA
China

1m/s=1.94 knots

Hodograph

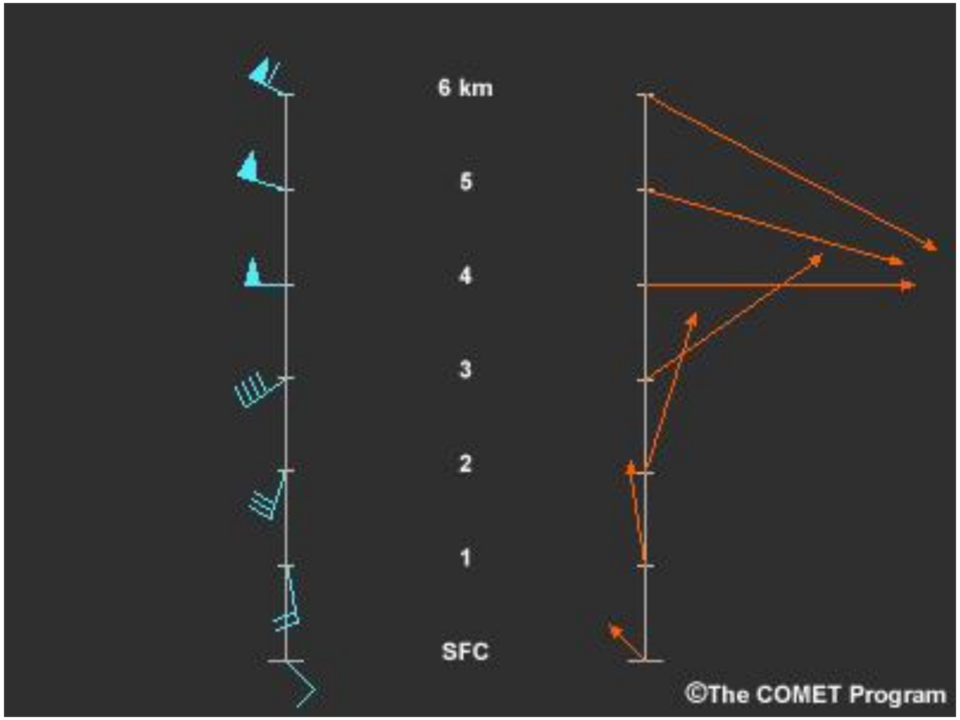
- 图形显示风垂直风切变
- 垂直风切变分析的重要性

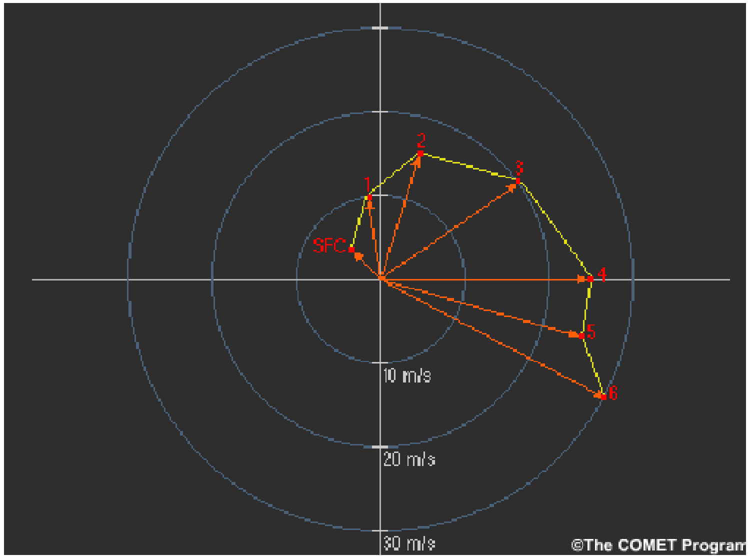
  可用于预测
  - 对流风暴的类型
  - 对流的组织特征
  - 超级单体风暴的可能性
  - 新单体的生成地点
  - 单体和对流系统的移动方向

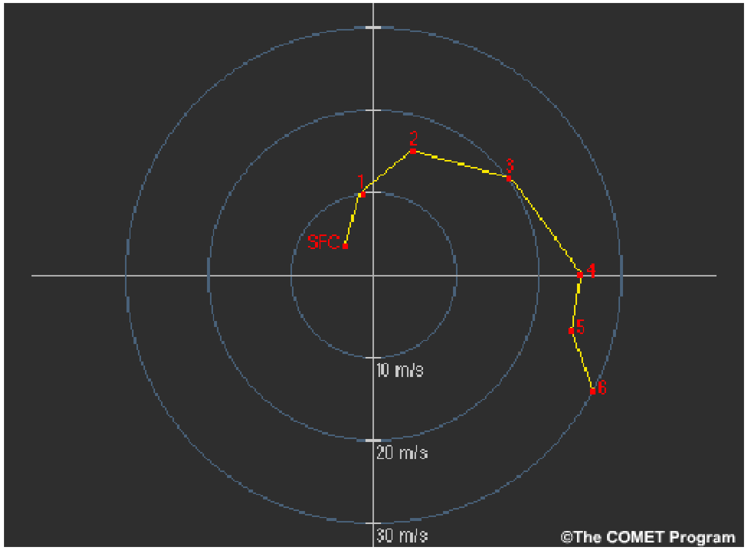


How to produce a hodograph?

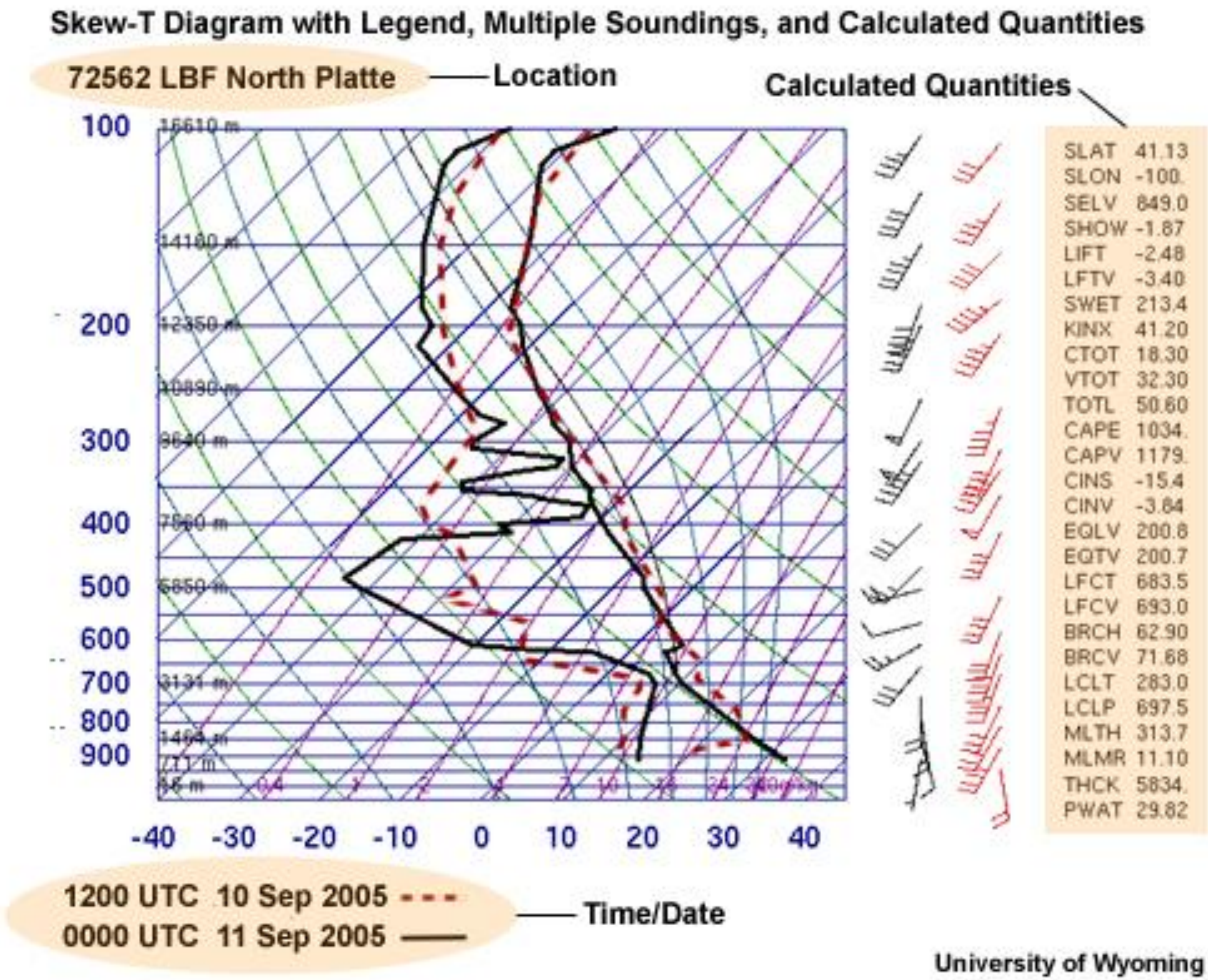
1. Convert wind barbs to wind vectors
2. Plot all wind vectors on a polar coordinate chart
3. Connect the end points of the wind vectors







Legend

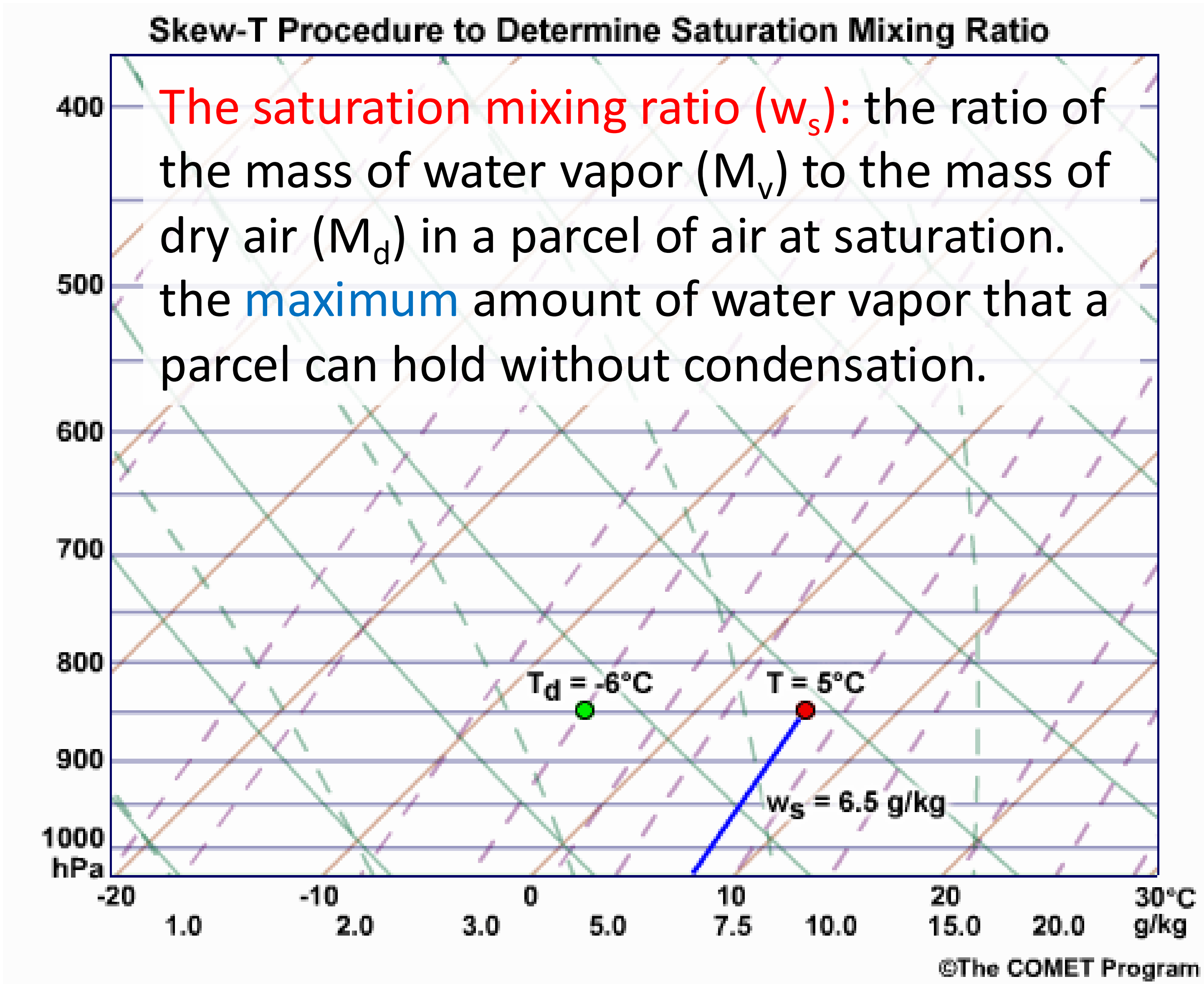


Skew-T Diagram with Legend, Multiple Soundings, and Calculated Quantities
72562 LBF North Platte
Location
Calculated Quantities
100
200
300
400
500
600
700
800
900
-40 -30 -20 -10 0 10 20 30 40
SLAT 41.13
SLON -100.
SELV 849.0
SHOW -1.87
LIFT -2.48
LFTV -3.40
SWET 213.4
KINX 41.20
CTOT 18.30
VTOT 32.30
TOTL 50.60
CAPE 1034.
CAPV 1179.
CINS -15.4
CINV -3.84
EQLV 200.8
EQTV 200.7
LFCT 683.5
LFCV 693.0
BRCH 62.90
BRCV 71.68
LCLT 283.0
LCLP 697.5
MLTH 313.7
MLMR 11.10
THCK 5834.
PWAT 29.82
1200 UTC 10 Sep 2005
0000 UTC 11 Sep 2005
Time/Date
University of Wyoming

Parameters: Moisture

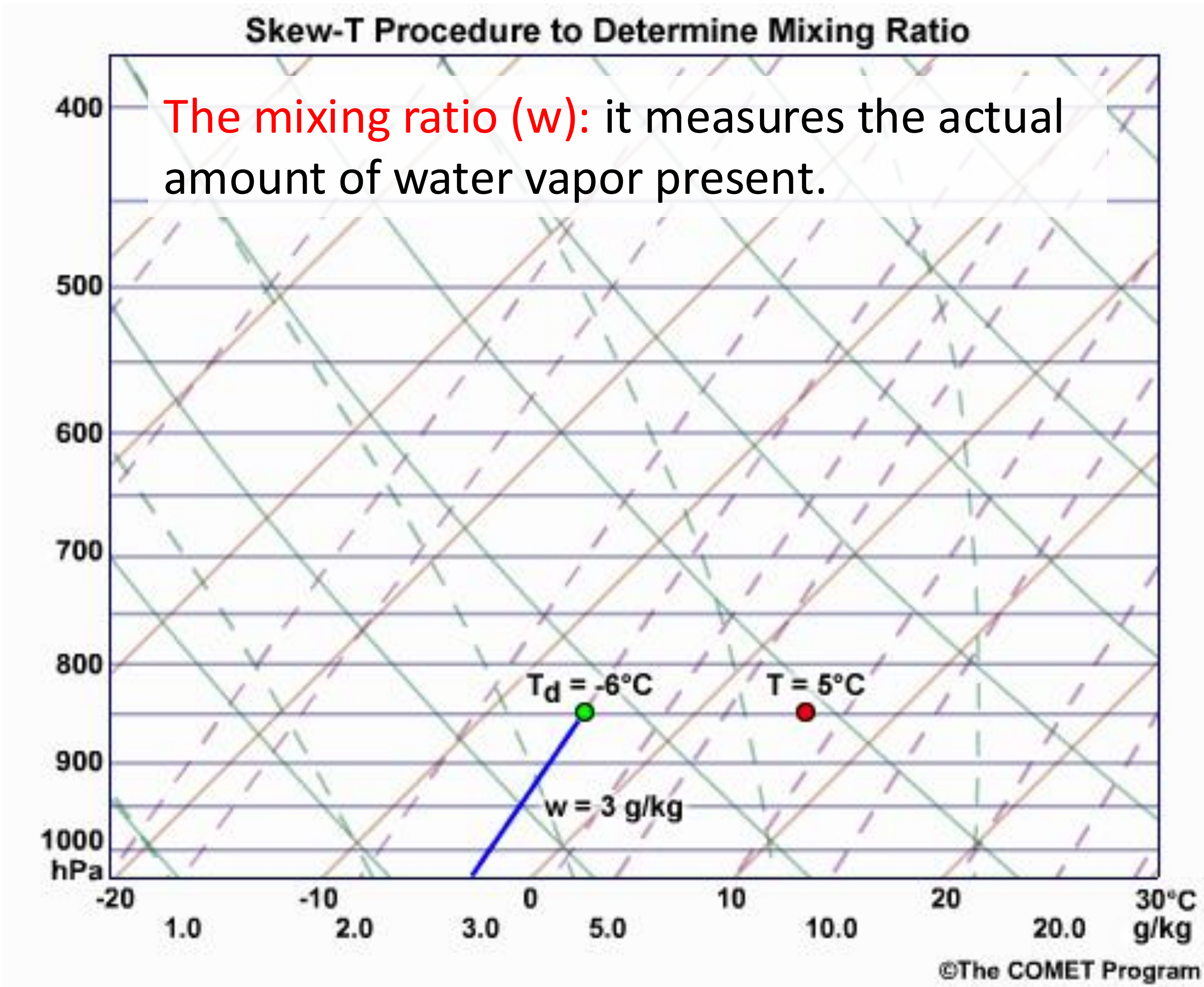
The saturation mixing ratio (w_s): the ratio of the mass of water vapor (M_v) to the mass of dry air (M_d) in a parcel of air at saturation.

the maximum amount of water vapor that a parcel can hold without condensation.



Parameters: Moisture

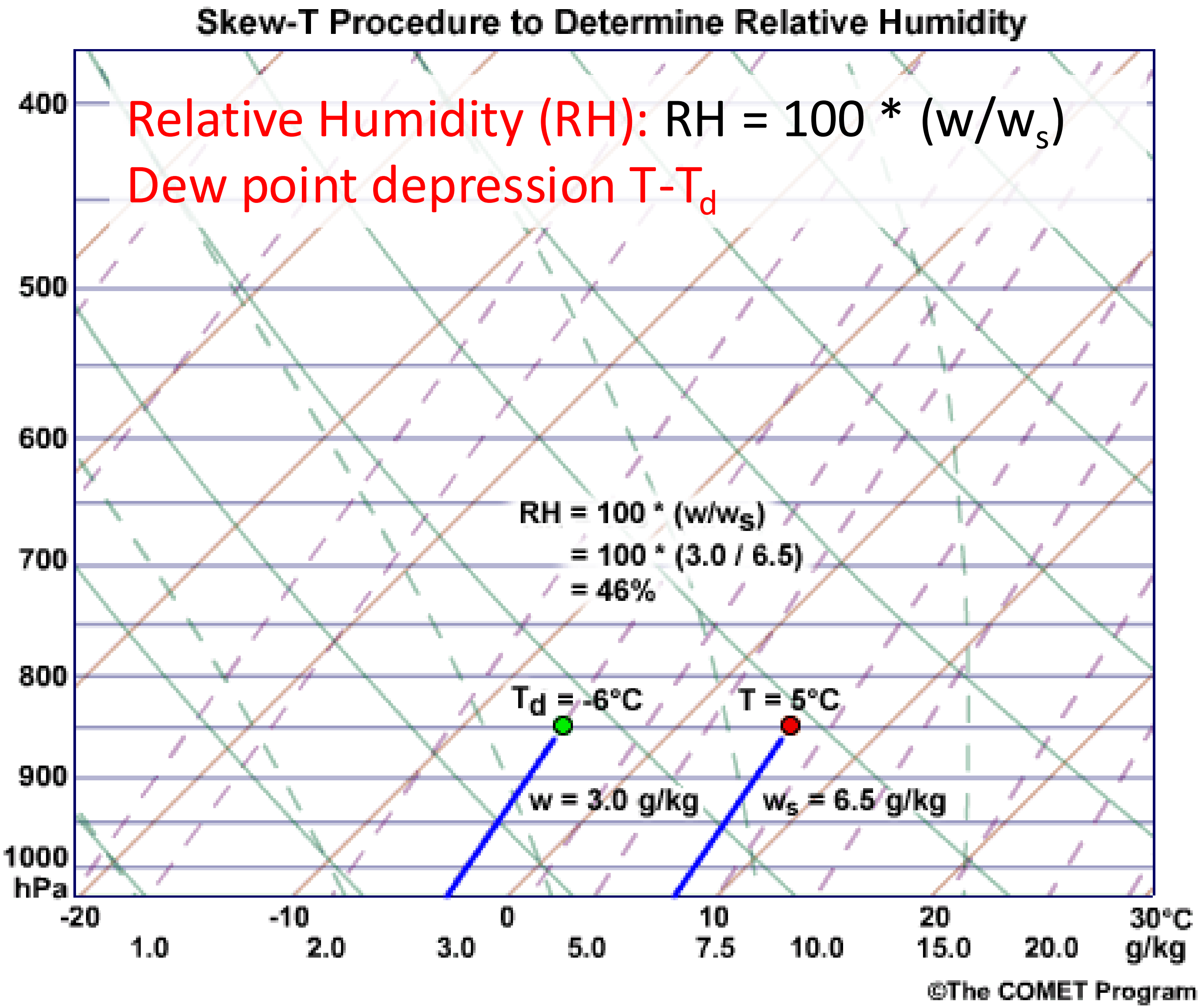
The mixing ratio (w): it measures the actual amount of water vapor present.



Parameters: Moisture

Relative Humidity (RH): $RH = 100 * (w/w_s)$

Dew point depression $T-T_d$



Parameters: Moisture

- The saturation vapor pressure (e_s) : that part of the total atmospheric pressure attributable to water vapor if the air were saturated.

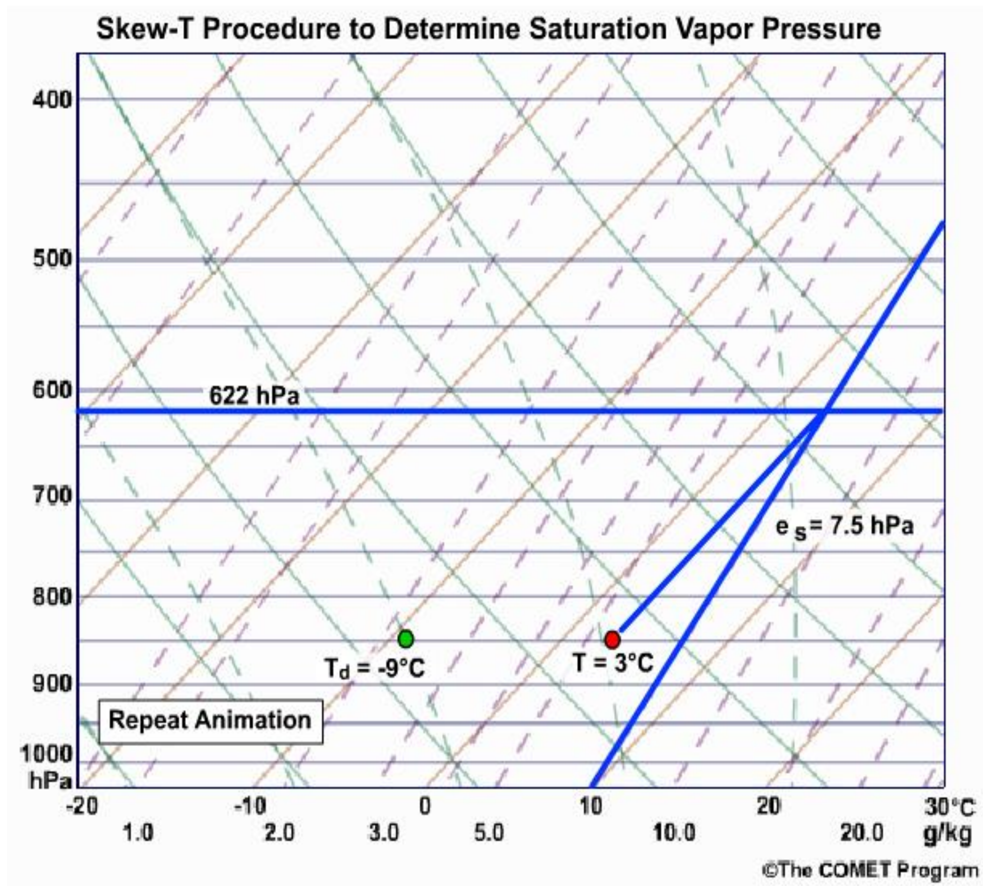
$$w_s = 0.622\frac{e_s}{p-e_s} \approx 0.622\frac{e_s}{p}$$

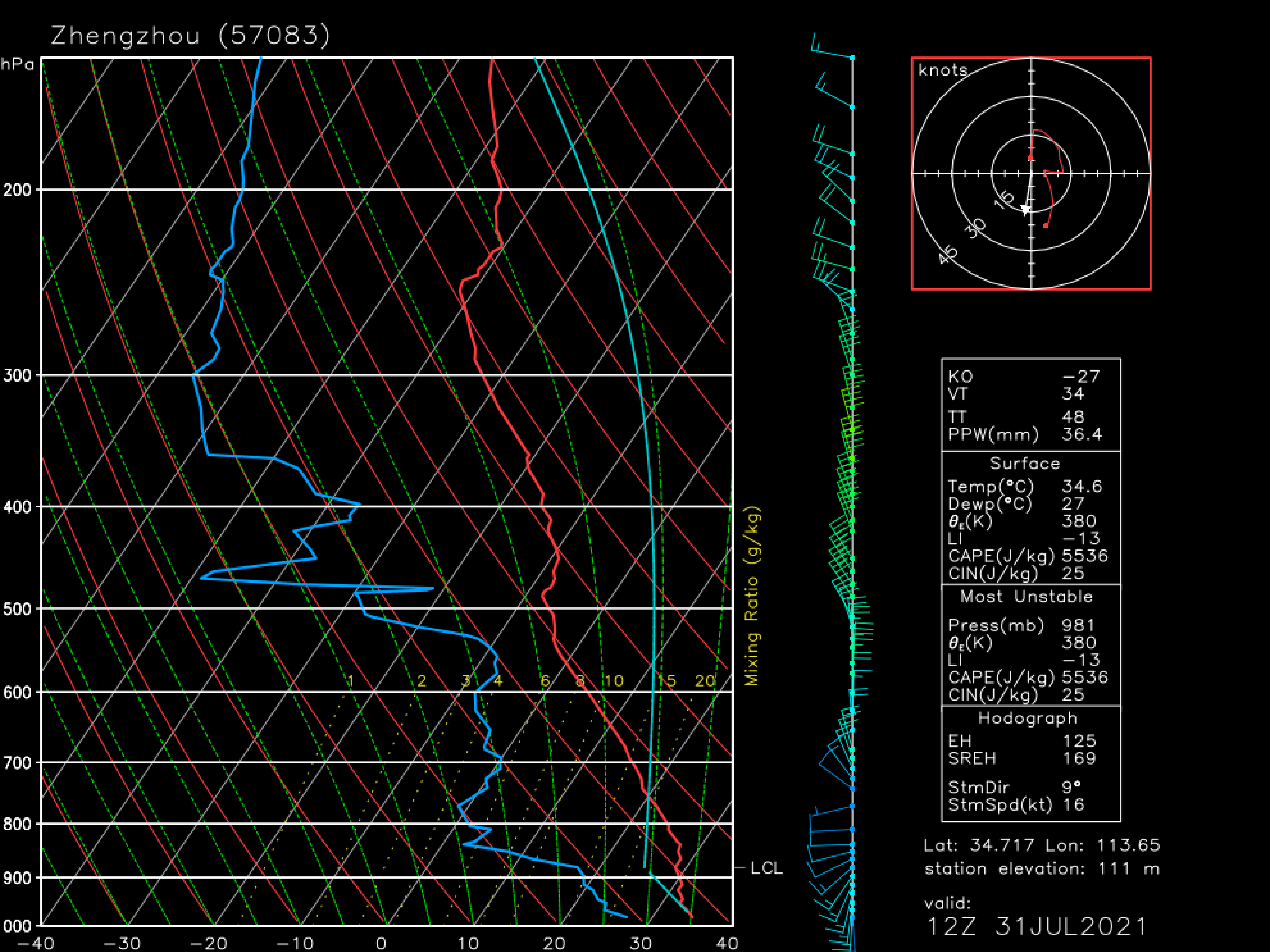
(kg/kg)

$$w_s = 622\frac{e_s}{p-e_s} \approx 622\frac{e_s}{p}$$

(g/kg)

- From the (T,P)follow the isotherm to the 622 hPa isobar. The value of the saturation mixing-ratio line through this point at 622 hPa (hPa).





Zhengzhou (57083)
hPa
200
300
400
500
600
700
800
900
000
−40
−30
−20
−10
0
10
20
30
40
1
2
3
4
6
8
10
15
20
Mixing Ratio (g/kg)
LCL
knots
15
30
45
KO −27
VT 34
TT 48
PPW(mm) 36.4
Surface
Temp(°C) 34.6
Dewp(°C) 27
θE(K) 380
LI −13
CAPE(J/kg) 5536
CIN(J/kg) 25
Most Unstable
Press(mb) 981
θE(K) 380
LI −13
CAPE(J/kg) 5536
CIN(J/kg) 25
Hodograph
EH 125
SREH 169
StmDir 9°
StmSpd(kt) 16
Lat: 34.717 Lon: 113.65
station elevation: 111 m
valid:
12Z 31JUL2021

Parameters: Moisture

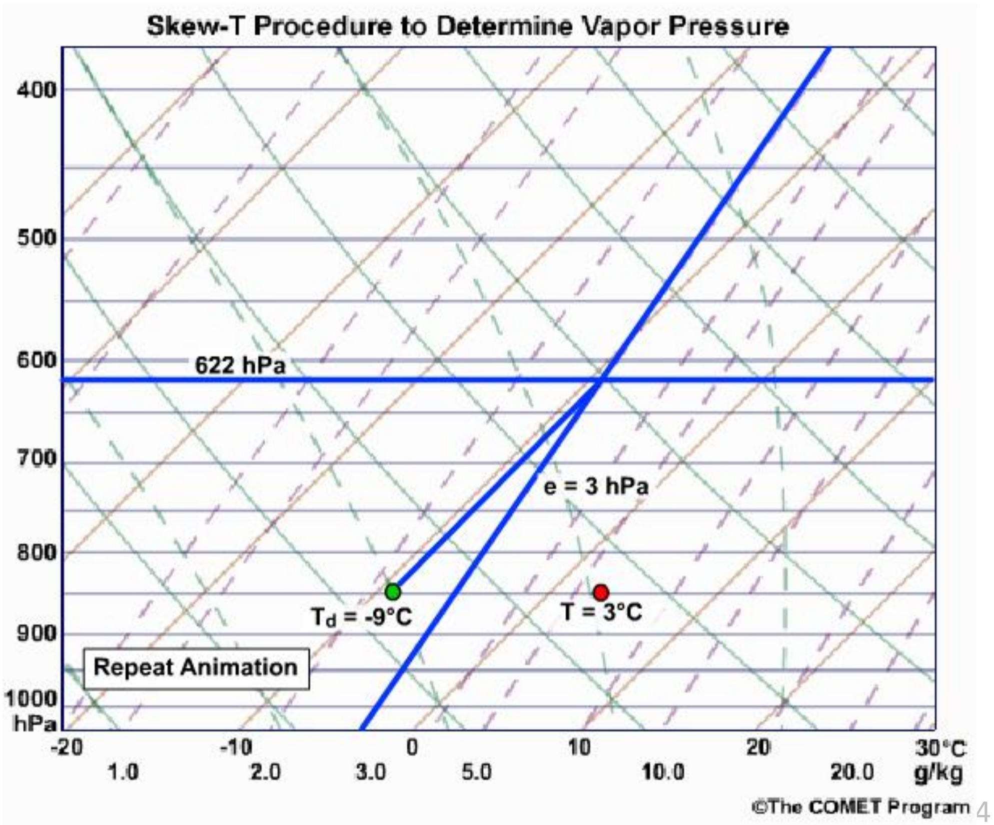
$$w = 0.622\frac{e}{p-e}$$

(kg/kg)

$$w = 622\frac{e}{p-e}$$

(g/kg)

- The vapor pressure (e) : that part of the total atmospheric pressure attributable to water vapor.
- From the T_d at the given pressure, follow the isotherm to the 622 hPa isobar. The value of the saturation mixing-ratio line through this point at 622 hPa gives the vapor pressure in hectopascals (hPa) at the given pressure



Parameters: Temperatures

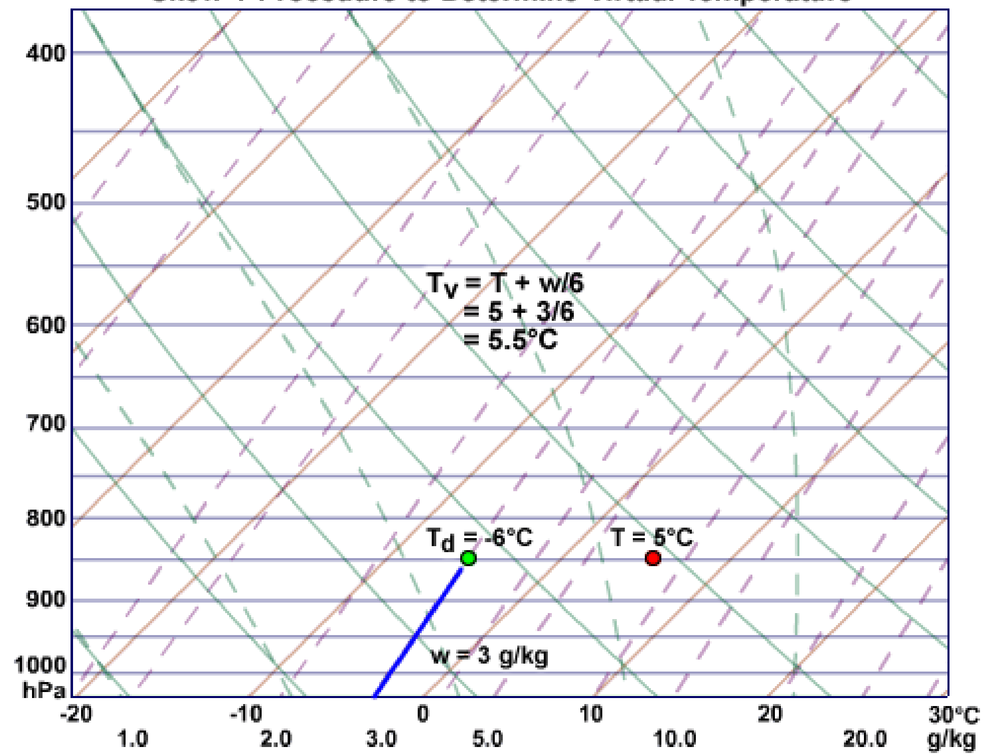
- The virtual temperature (T_v) is the temperature at which dry air would have with the same density as the moist air, at a given pressure.

$$p = \rho R_d T_v$$

$$T_v = T(1 + 0.61w) \quad \text{kg/kg} \quad \text{K}$$

$$T_v \sim T + w/6 \quad \text{g/kg} \quad {}^\circ\text{C}$$

Skew-T Procedure to Determine Virtual Temperature

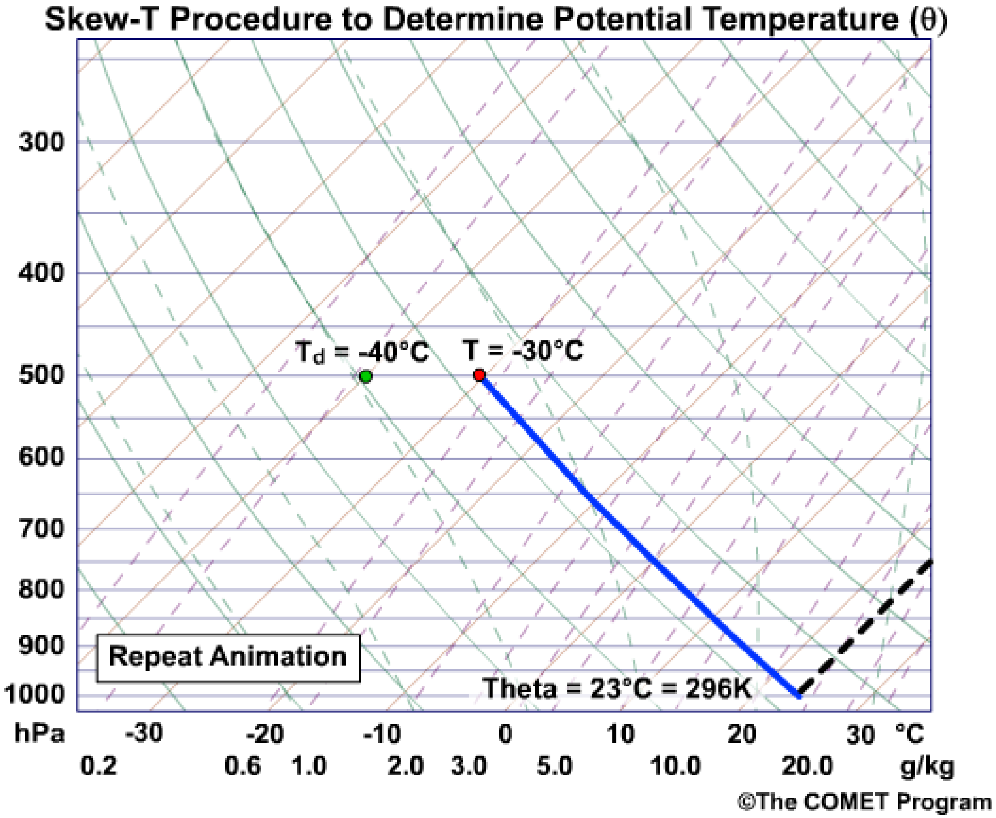


©The COMET Program

Parameters: Temperatures

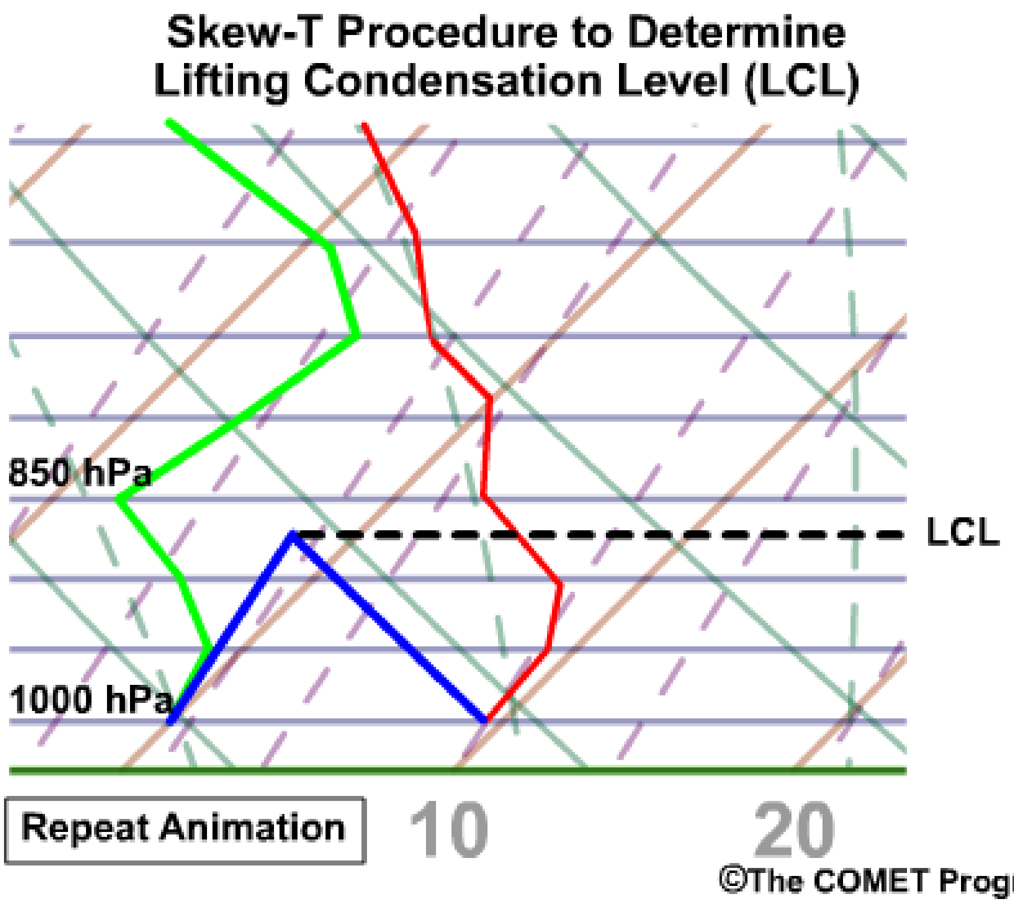
The potential temperature (theta) is the temperature that a sample of air would have if it were brought dry-adiabatically to a pressure of 1000 hPa.

$$\theta = T\left(\frac{1000}{p}\right)^{\frac{R}{C_p}}$$



Levels

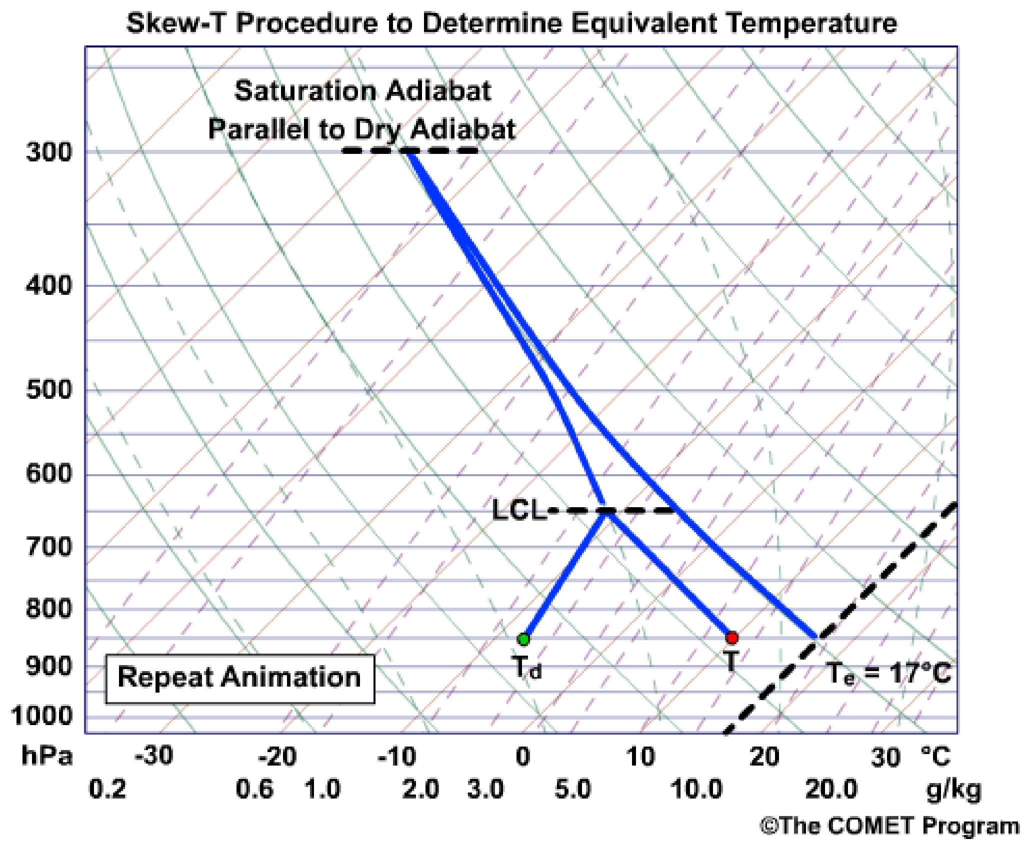
The lifting condensation level (LCL) is the height at which a parcel of air becomes saturated when it is lifted dry-adiabatically.



Parameters: Temperatures

The equivalent temperature (T_e) is the temperature at a level that a sample of air would have if all its moisture were condensed out by a pseudo-adiabatic process

$$T_e = T\left(1 + \frac{Lq_s}{C_p T_{LCL}}\right)$$

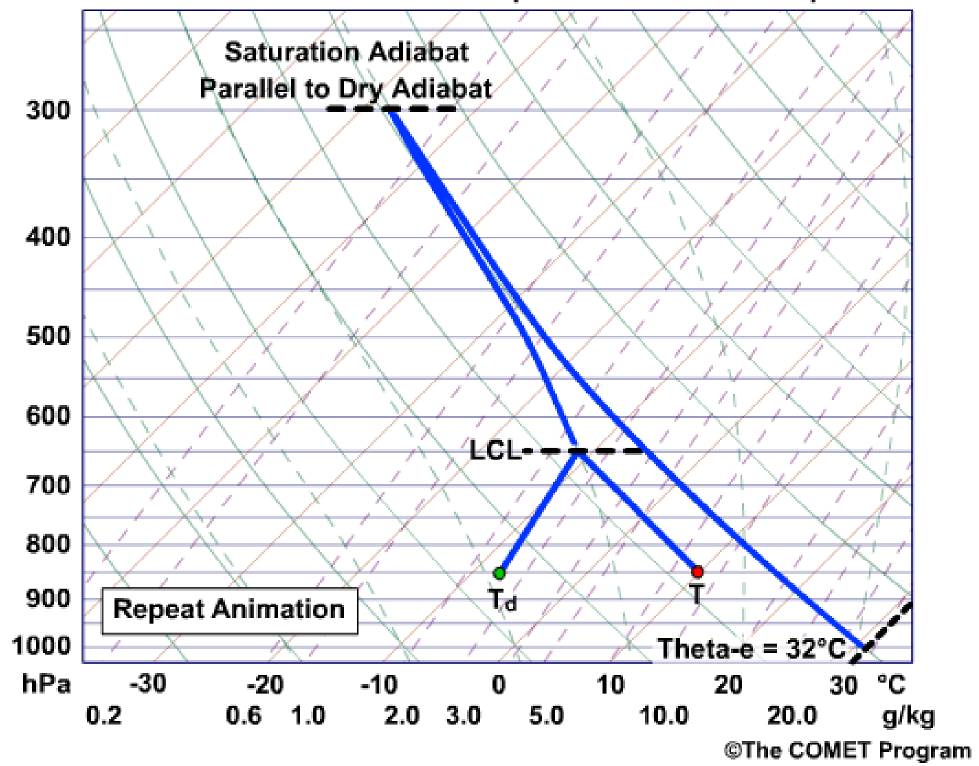


相当温度：1千克湿空气中所含的水汽（比湿），在气压不变的情况下，全部凝结，释放的潜热使空气增暖所达到的温度。

Parameters: Temperatures

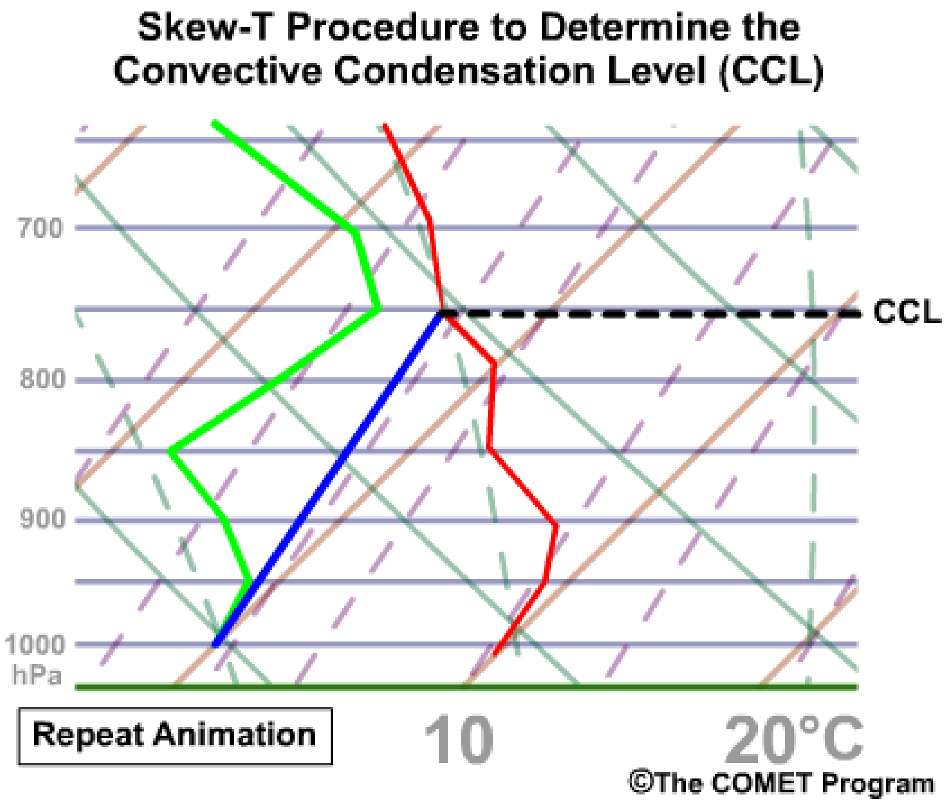
The equivalent potential temperature (theta-e) is the temperature a sample of air would have if all its moisture were condensed out by a pseudo-adiabatic process and the sample then brought dry-adiabatically back to 1000 hPa.

$$\theta_e = \theta\left(\frac{1 + Lq_s}{c_p T_{LCL}}\right)$$



Levels

The convective condensation level (CCL) is the height to which a parcel of air, if heated sufficiently from below, will rise adiabatically until it is just saturated. Usually, it is the height of the base of cumuliform clouds produced by thermal convection caused solely by surface heating.

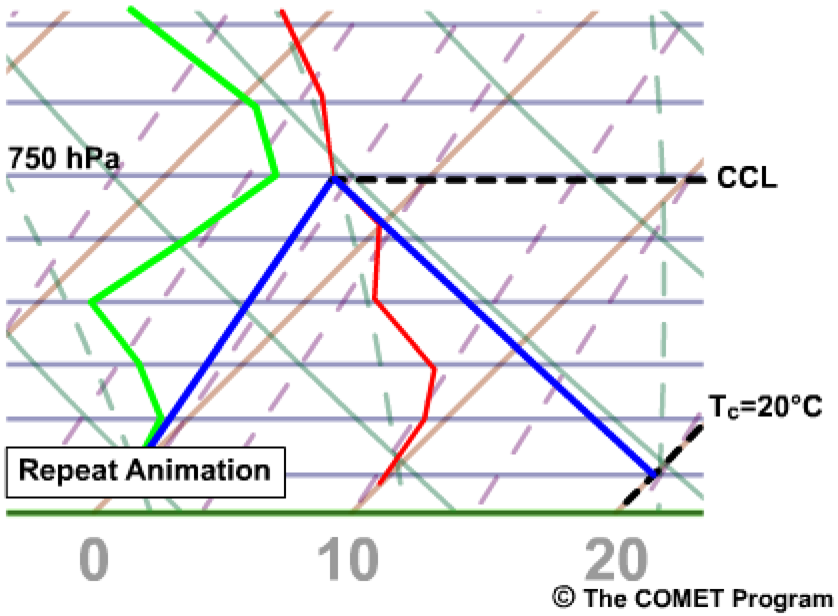


Parameters: Temperatures

The convective temperature (T_c) is the surface temperature that must be reached to start the formation of convective clouds caused by solar heating of the near-surface layer.

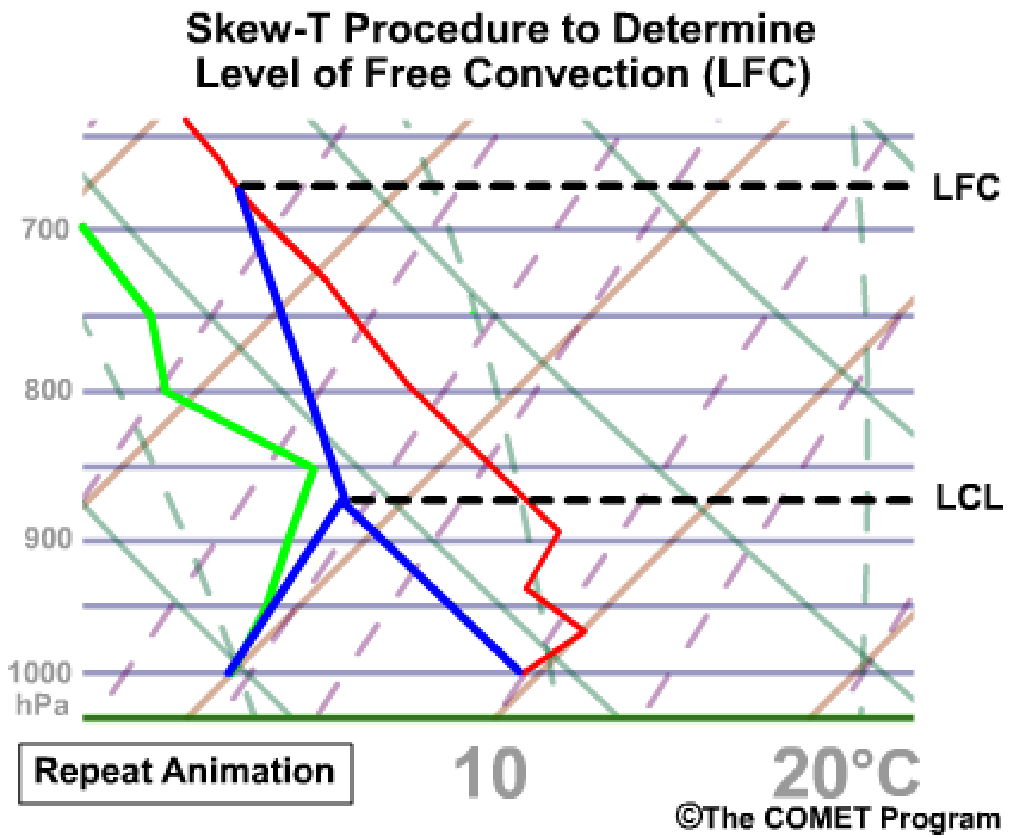
From the [convective condensation level (CCL)] on the temperature profile, proceed downward along a [dry adiabat] to the surface-pressure isobar. The temperature read at this intersection is the convective temperature (T_c).

Skew-T Procedure to Determine Convective Temperature



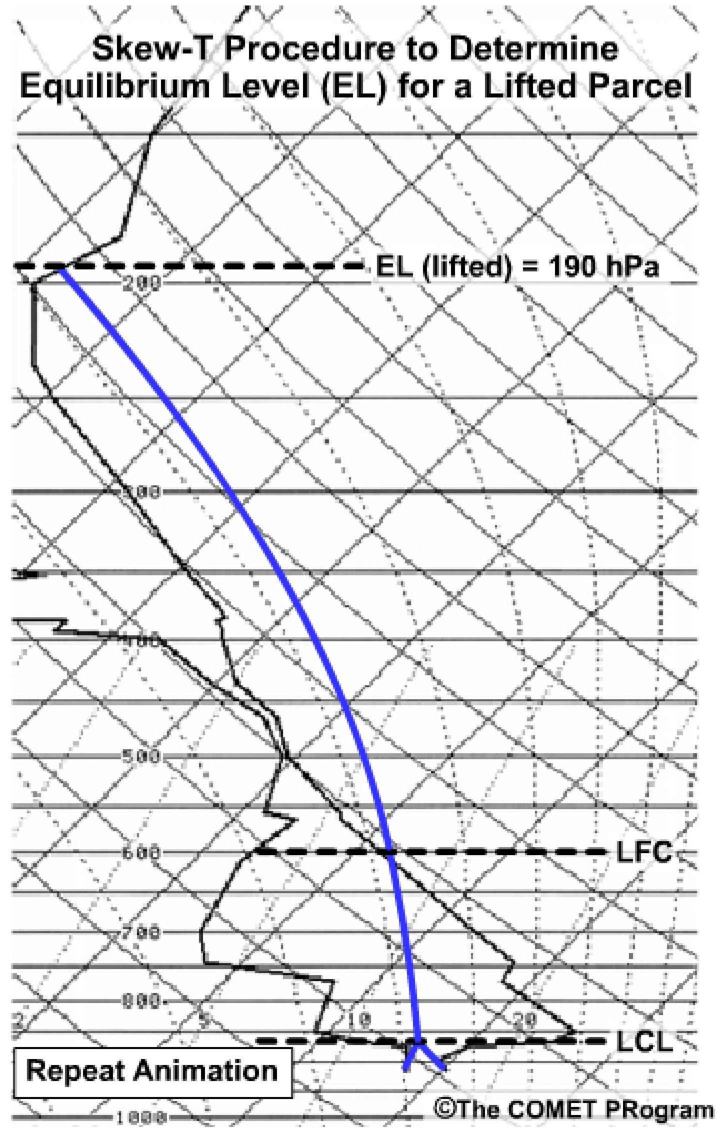
Levels

The level of free convection (LFC) is the height at which a parcel of air, when lifted, becomes warmer than its surroundings and thus convectively buoyant.



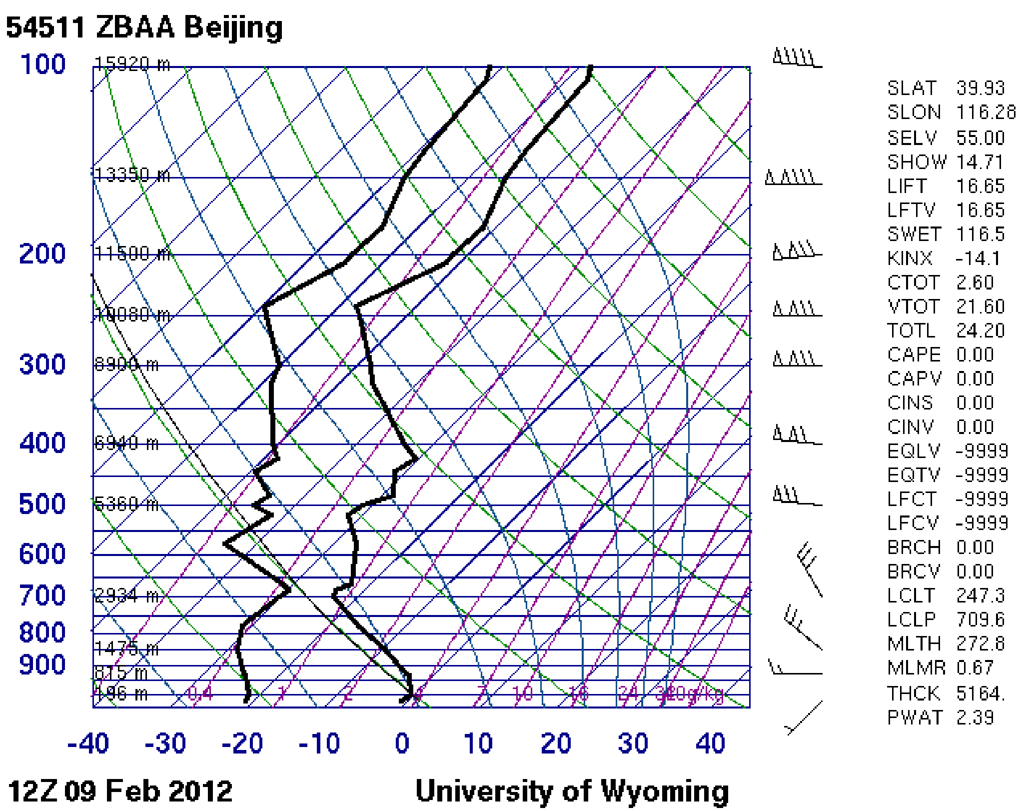
Levels

The equilibrium level (EL) is the height where the temperature of a buoyantly rising parcel again equals the temperature of the environment.



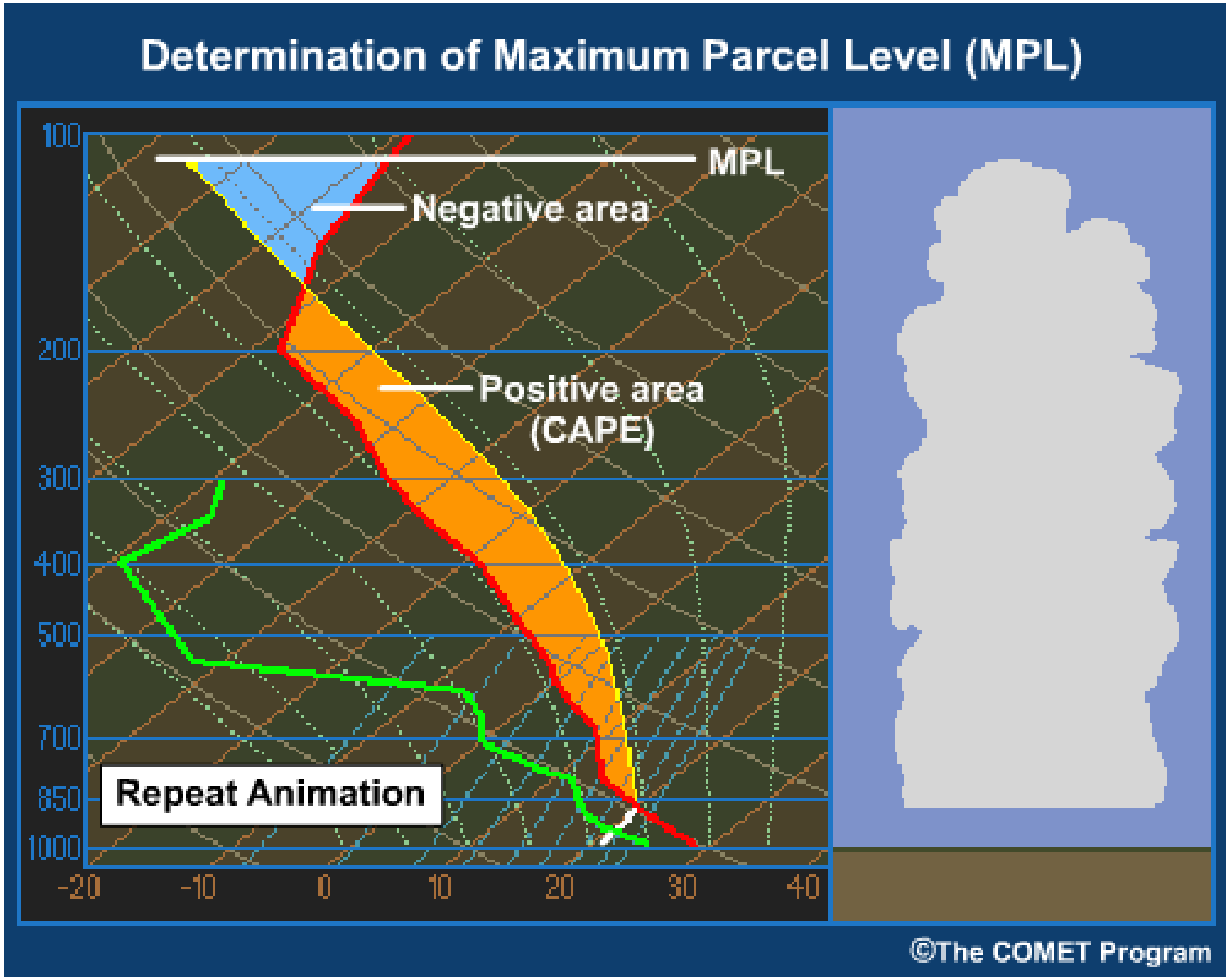
Levels

The tropopause is defined as the boundary between the troposphere and the stratosphere. It is usually marked by a significant change in lapse rate from less stable below in the troposphere to very stable above in the stratosphere.



Levels

The maximum parcel level (MPL) is the level to which a parcel will travel before exhausting all of its upward momentum.

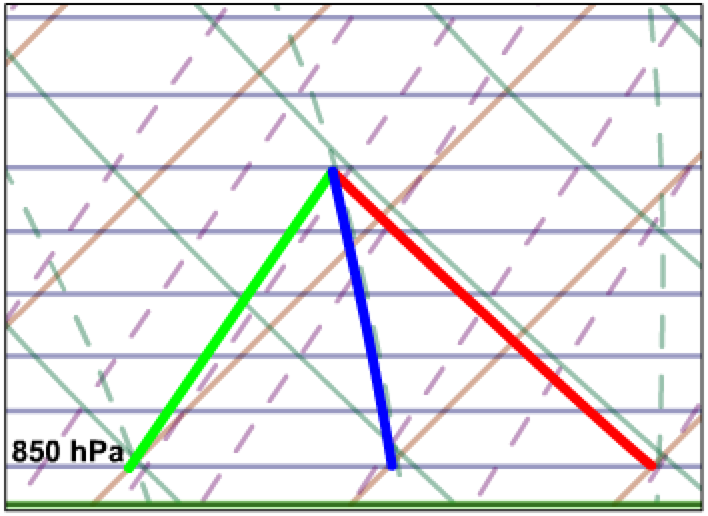


Parameters: Temperatures

The wet-bulb temperature is the temperature to which a parcel of air at a constant pressure cools through the evaporation of water into it. At this temperature, the parcel becomes saturated.

$$T_w = T - L\frac{w_s - w}{c_p}$$

Skew-T Procedure to Determine Wet-bulb Temperature

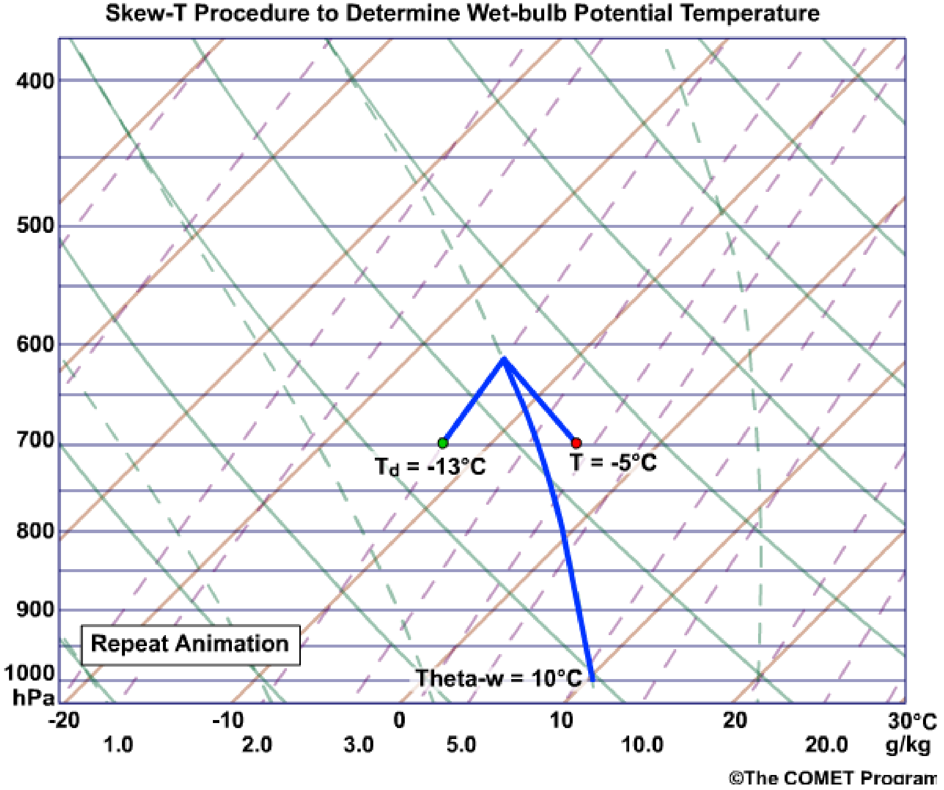


From LCL, proceed down the [saturation adiabat](#) to the original level.

Parameters: Temperatures

The wet-bulb potential temperature (theta-w) is the wet-bulb temperature a sample of air would have if it were brought along a saturation adiabat to a pressure of 1000 hPa.

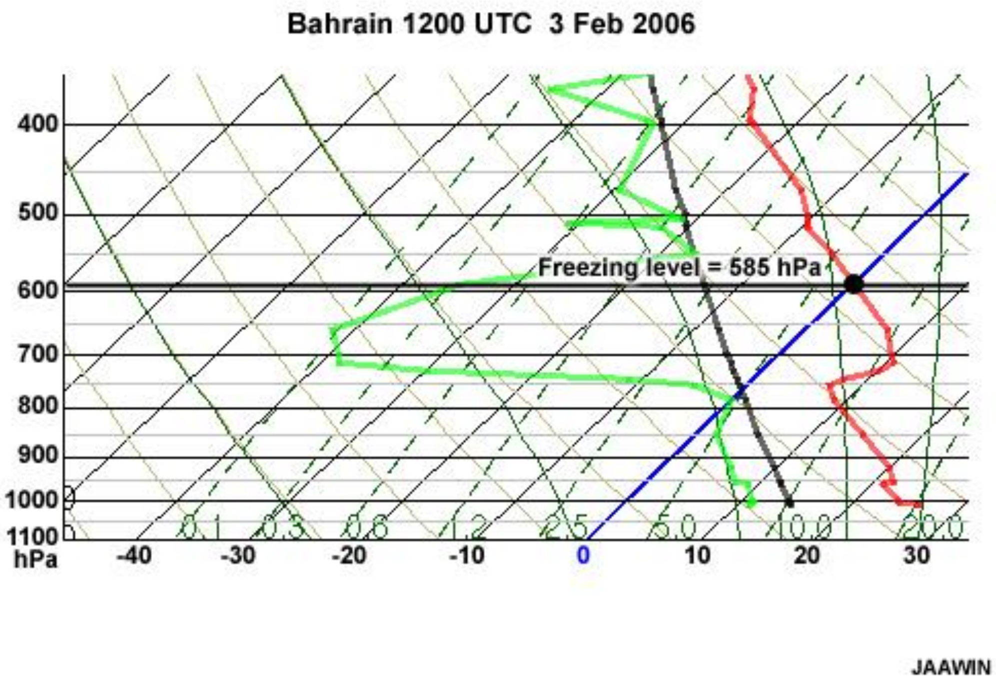
$$\theta_w = T_w\left(\frac{1000}{p}\right)^{\frac{R}{c_p}}$$



From LCL, proceed down the saturation adiabat to 1000hPa.

Levels

The freezing level is the **lowest** level in a sounding at which a temperature of 0° C is reported.

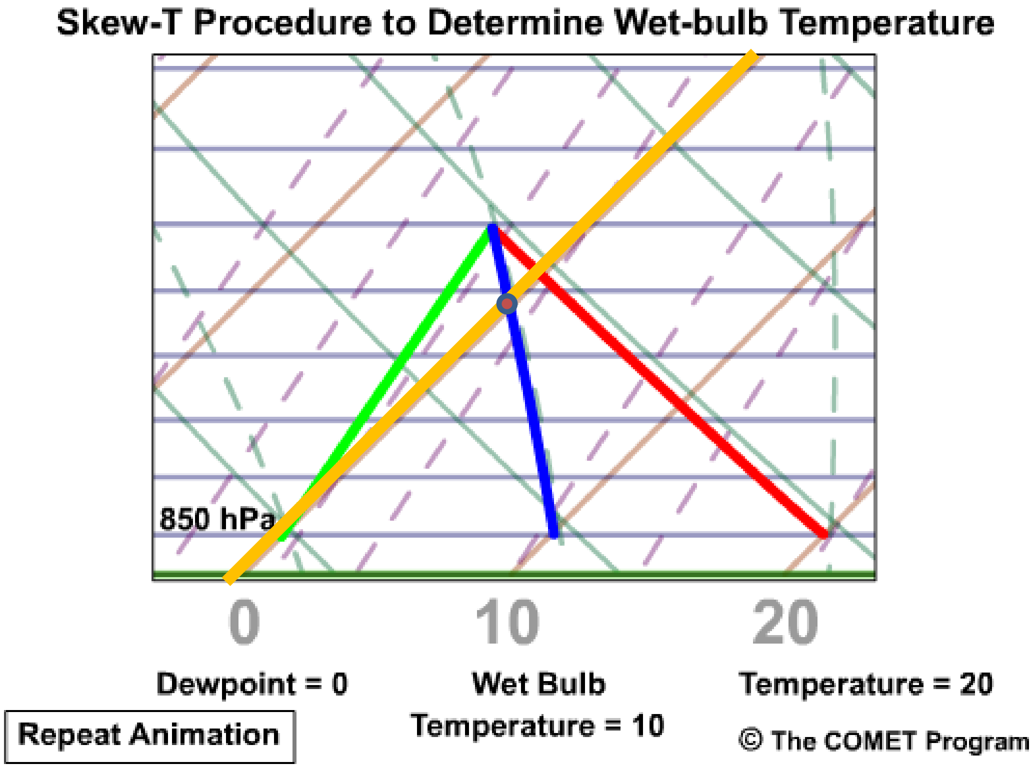


Significance:

- precipitation type
- A low FRZ level indicates hailstones will have more time to grow in the updraft and will have less time to melt as it falls to the surface.

Levels

The wet-bulb zero level is the lowest level in a sounding at which the [wet-bulb temperature] is 0° C.



references

- Skew-T Mastery (ucar.edu)