Skew T – log P Diagram: Sounding Analysis

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UNIVERSITÀ DEGLI STUDI DI TORINO

Reading Assignment

- **The Use of the Skew-T, Log P Diagram in Analysis and Forecasting (TR79-006)**

  http://wx.erau.edu/reference/text/Tr79-006.pdf

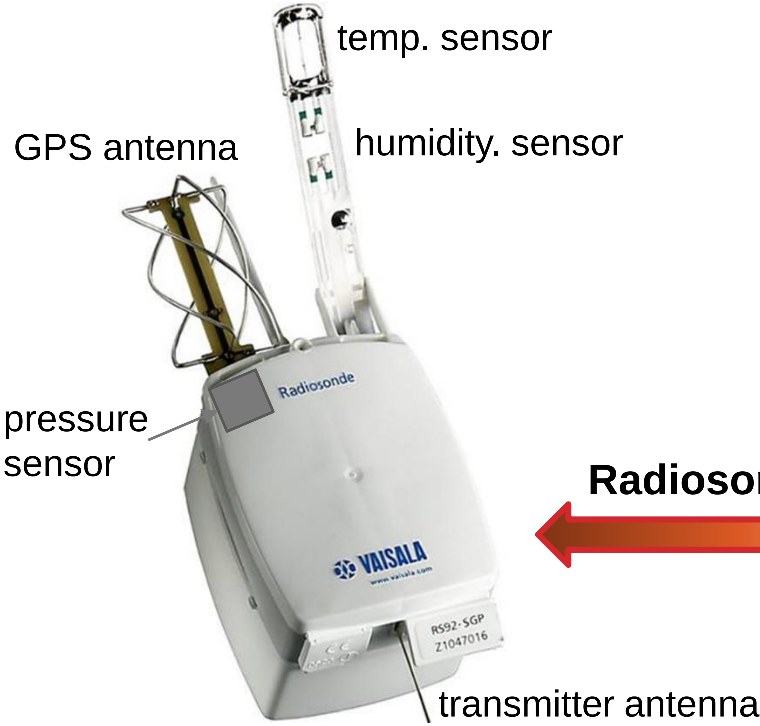
- **U. of Washington: SKEW-T, LOG-P DIAGRAM ANALYSIS PROCEDURES**

  http://www.atmos.washington.edu/~houze/301/Miscellaneous/Skew-T.pdf

Upper Air Observation

Radiosonde

- An instrument package lifted by a balloon with sensors for pressure, temperature, humidity.



(UCAR)

Upper Air Observation

Pibals (Pilot Balloons)

- Carry no instrument.
- Are usually tracked with theodolite.
- The balloon is assumed to rise at a constant rate once the correct amount of gas is placed in the balloon.
- By knowing the time of flight and the elevation and azimuth angle to the balloon, the position of the balloon, thus the wind speed and direction at various heights can be obtained.

(circa 1944)

(http://www.photolib.noaa.gov/)

Upper Air Observation

Rawinsonde

Radiosonde being carried aloft (circa 1997)

- A radiosonde that is tracked to provide wind information.
- Tracked by either a radar, a radiotheodolite, or by GPS.

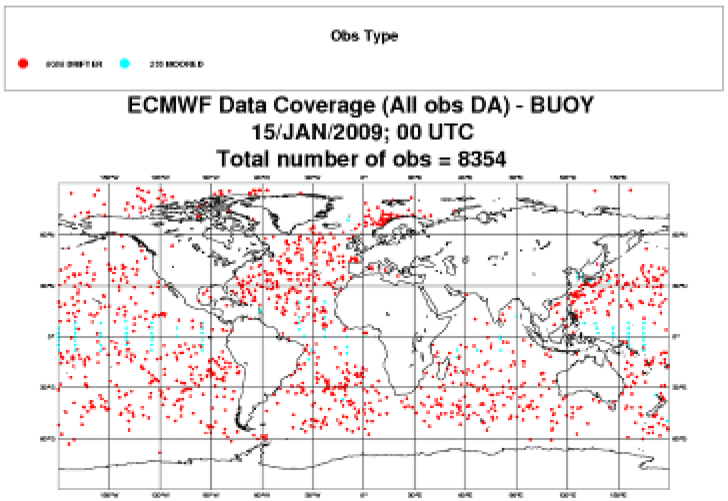
NWS Automated Radiotheodolite (circa 1955)

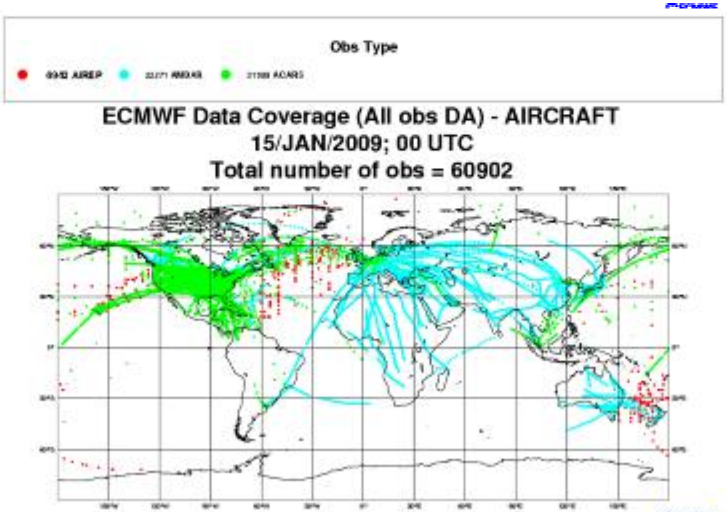
(http://www.ua.nws.noaa.gov/photo.htm)

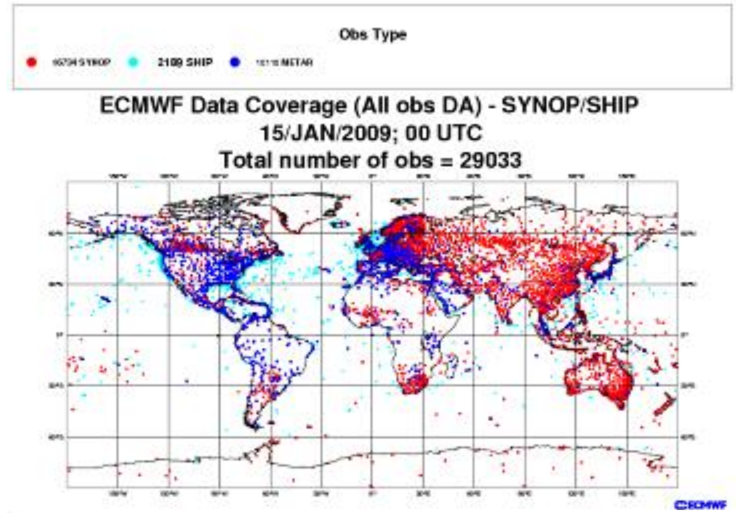
Observing networks for meteorological data

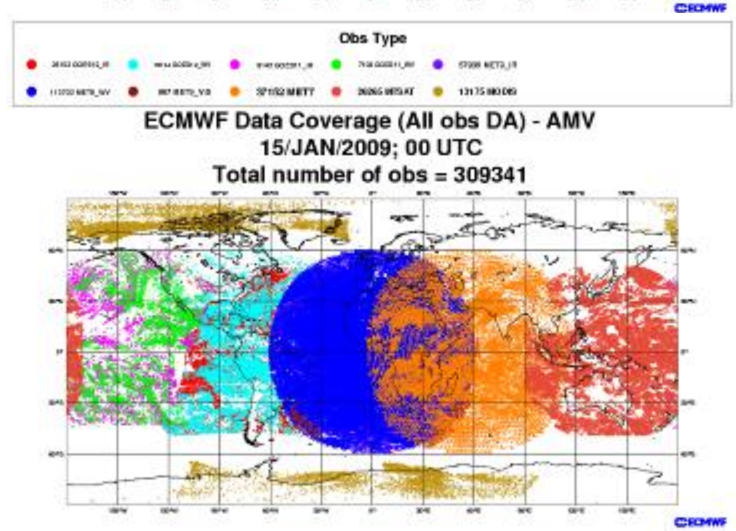
Observations **at synoptic scale**: each hour, at the main synoptic hours (00, 06, 12, 18 UTC), except rain (9, 21 LT)

Compose the WWW (World Weather Watch)



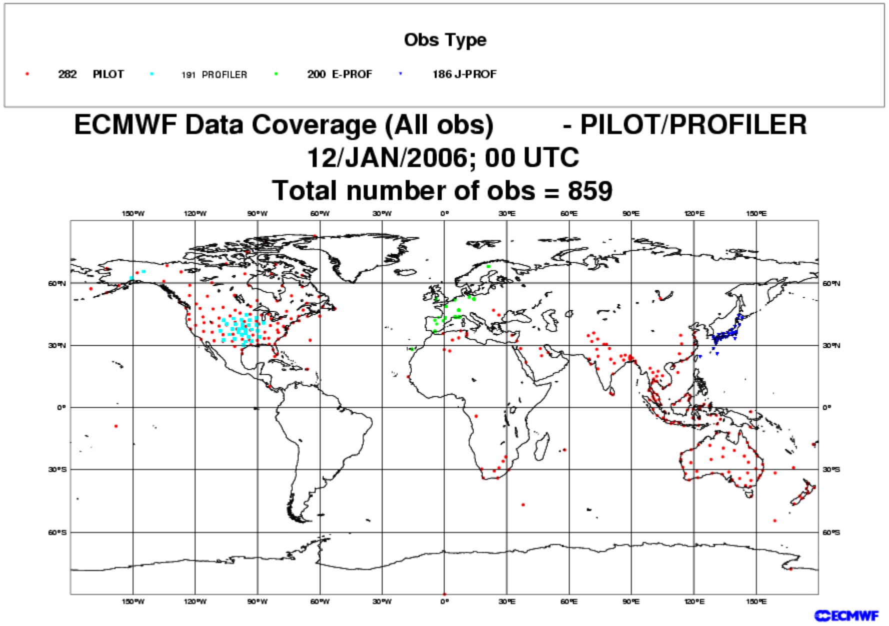


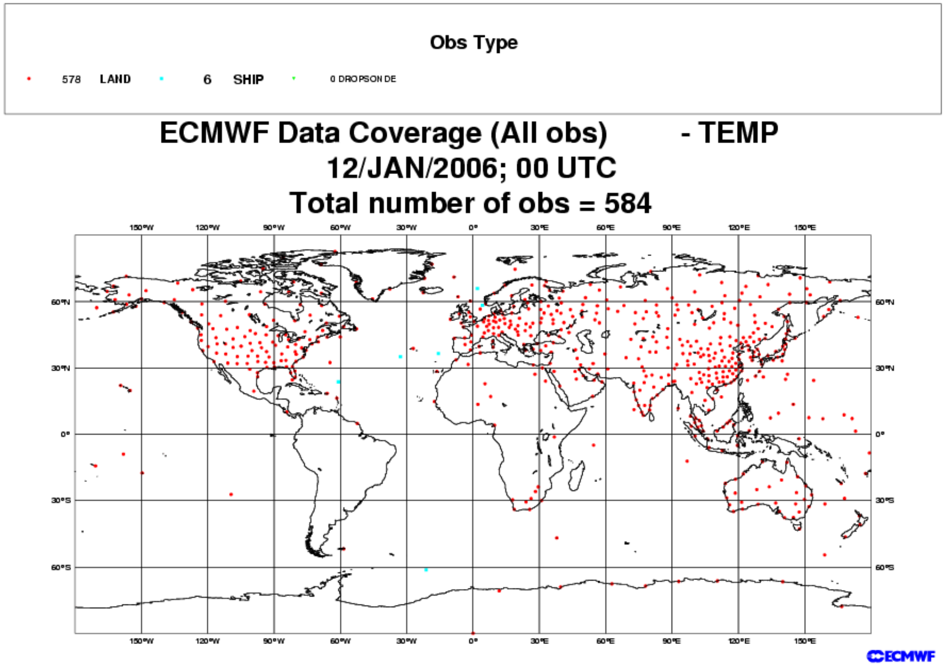




Observing networks for meteorological data

PILOT: balloons which measure wind





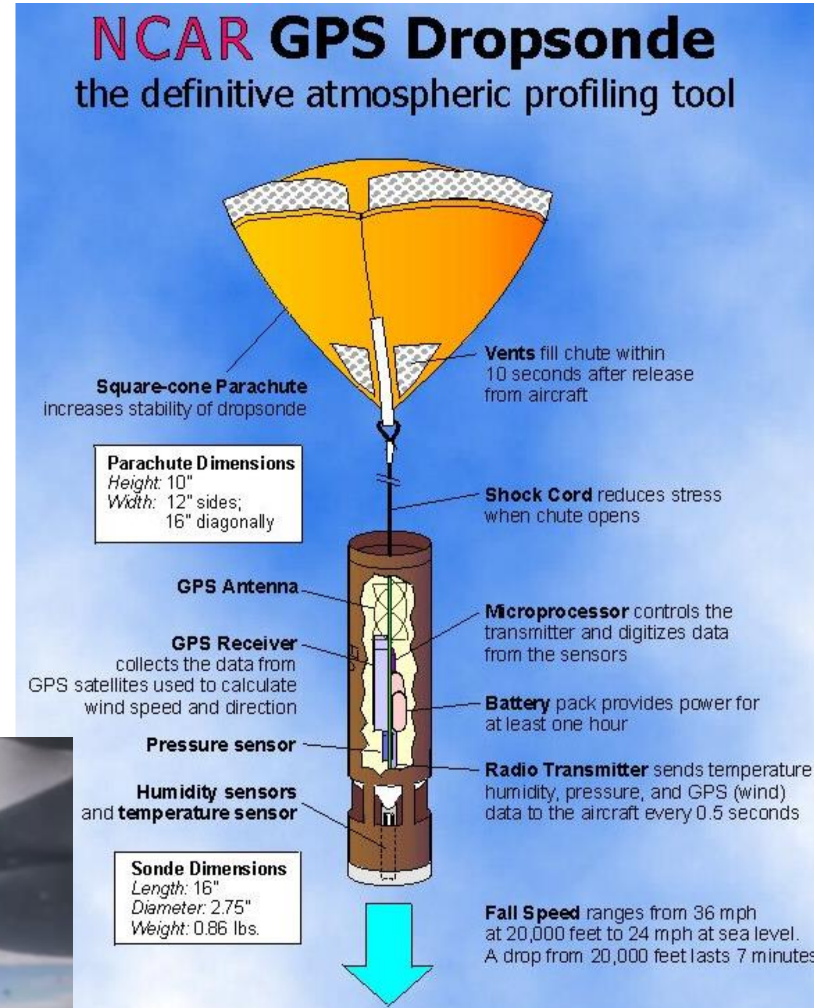
TEMP: radiosoundings with balloons (00, 12 UTC and sometimes 06, 18 UTC): measure T, RH, p, u, v, w

Upper Air Observation

Dropwindsonde

- Dropped from an aircraft or from a constant pressure balloon.
- Used for collecting data inside tropical cyclones.

(The Weather Channel; youtube.com)

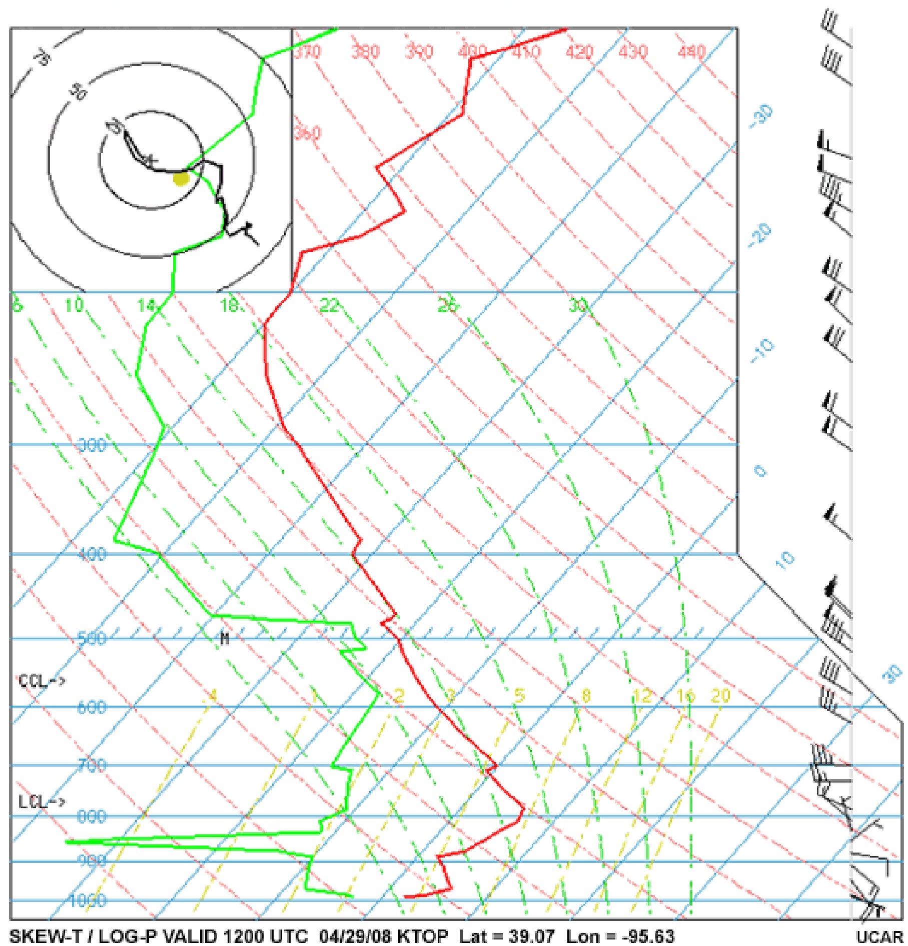


(http://typhoon.as.ntu.edu.tw/DOTSTAR/)

Upper Air Observation

Sounding data can be plotted on thermodynamic diagrams

- Stuve diagram
- Emagram
- Tephigram
- Skew T–log P diagram

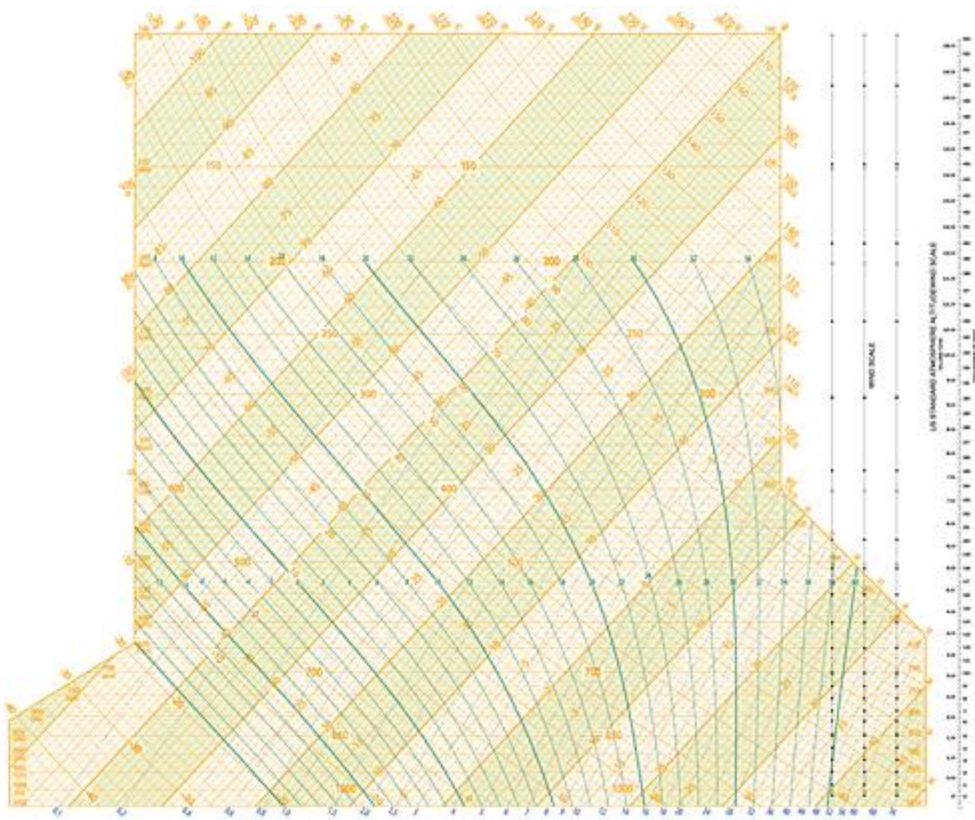


http://www.meted.ucar.edu/

Skew T – Log P Diagram

Full diagram

- Pressure (Isobars)
- Temperature (Isotherms)
- Dry Adiabats
- Moist (or Saturated) Adiabats
- Mixing Ratio
- Wind Staff

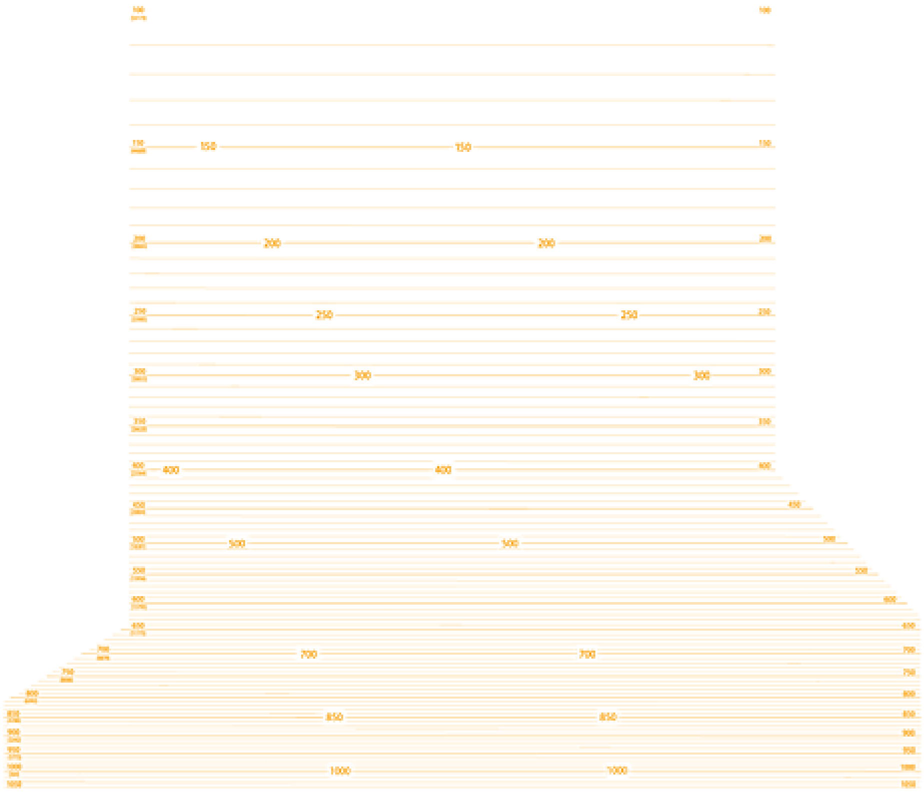


http://www.srh.noaa.gov/jetstream/

Skew T – Log P Diagram

Pressure (Isobars; mb)

- Pressure lines are drawn in the horizontal.
- Distance between the lines increases from the bottom to the top of the chart (1050 mb) to the top (100 mb).
- This is due to the decrease in atmospheric density with increasing elevation.
- Atmospheric pressure decreases logarithmically with increasing elevation. ➔ **"Log P"**

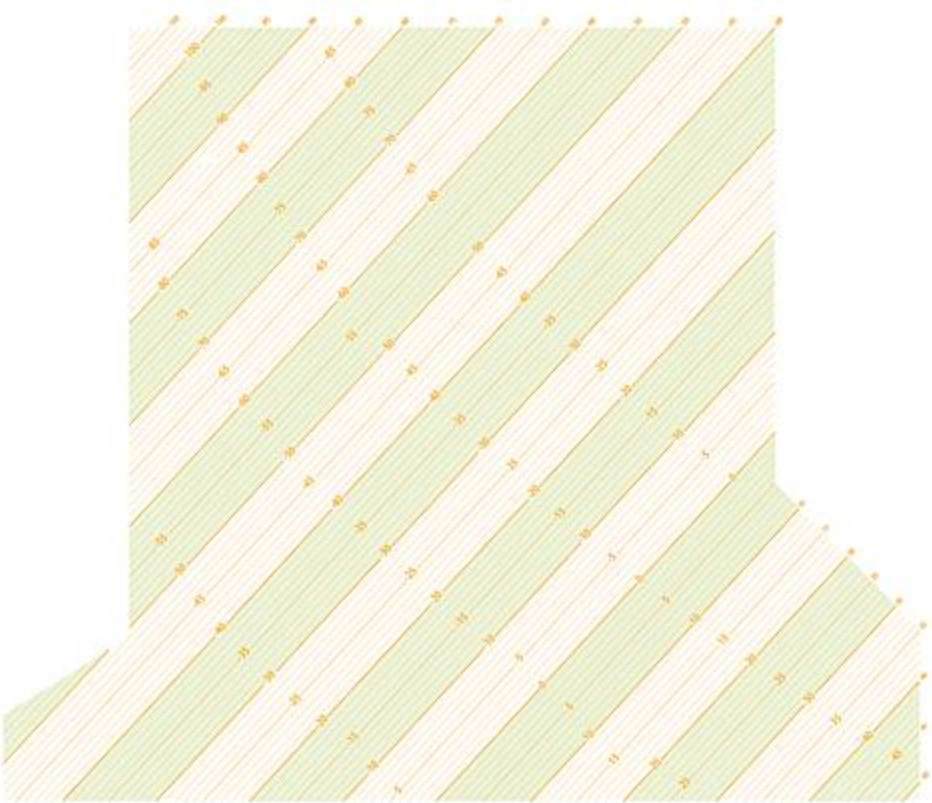


http://www.srh.noaa.gov/jetstream/

Skew T – Log P Diagram

Temperature (Isotherms; °C)

- Temperature lines are drawn at a 45° angle with temperature values that increase from the upper left to the lower right corner. ➔ "**Skew T**"



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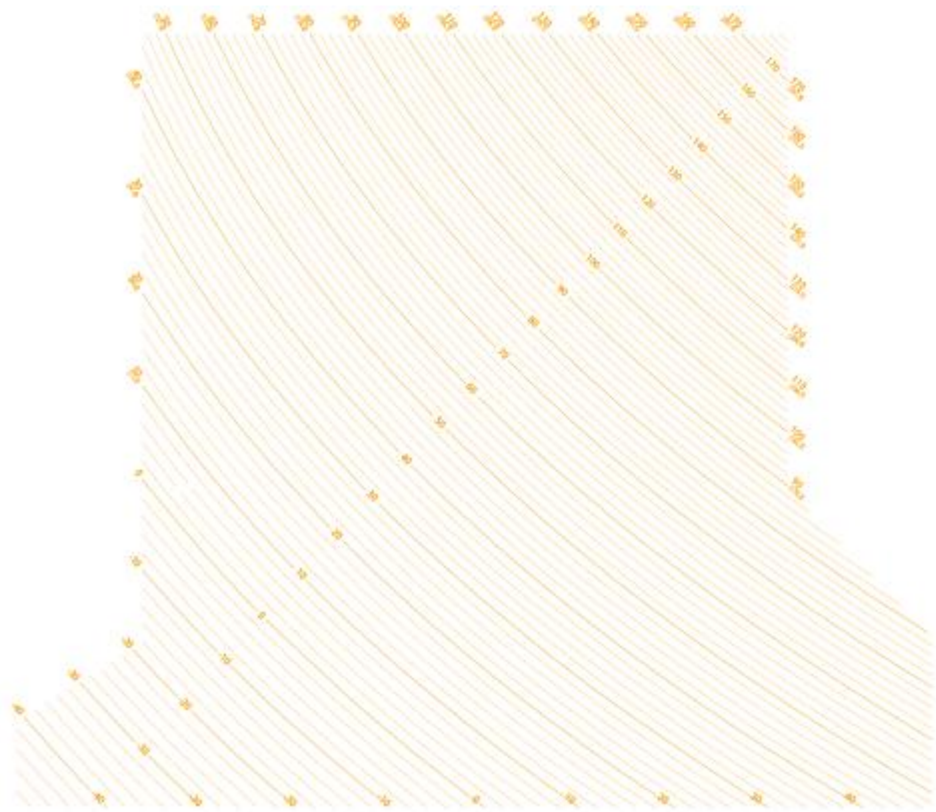
Skew T – Log P Diagram

Dry Adiabats

- Slightly curved, these lines increase in value (°C) from lower left to upper right.
- Dry adiabats represent the rate at which unsaturated air cools as it rises.
- As unsaturated air rises, it expands and cools with the temperature decreasing (or lapses) at a rate of 9.8°C per 1000 m (or 1 km).
- This rate is called the "**dry adiabatic lapse rate**" and these lines on the Skew-T represent that value.
- These are also line of constant potential temperature (θ).

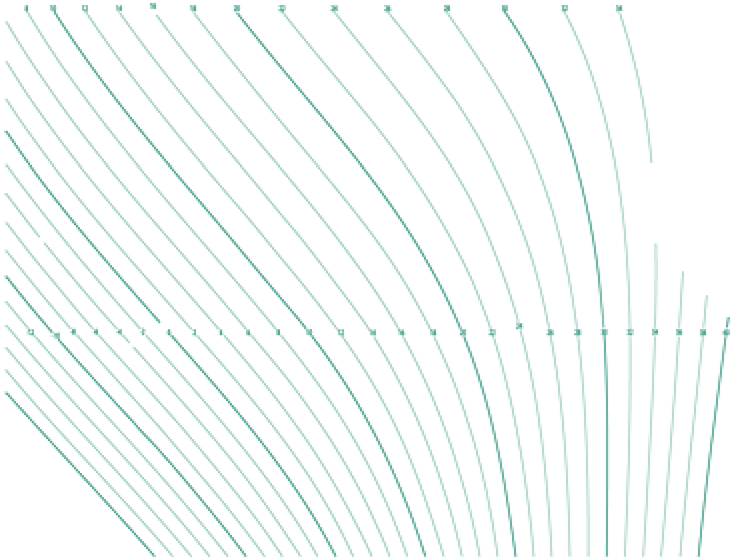


http://www.srh.noaa.gov/jetstream/

Skew T – Log P Diagram

Moist (or Saturated) Adiabats

- These curved lines increase in value (°C) from left to right.
- Moist adiabats represent the rate at which saturated air cools (lapses) as it rises.
- When the air is at RH=100%, further cooling causes water vapor to condense.
- In this condensation process, heat is released. This heat affects the rate of cooling and these lines represent that rate.

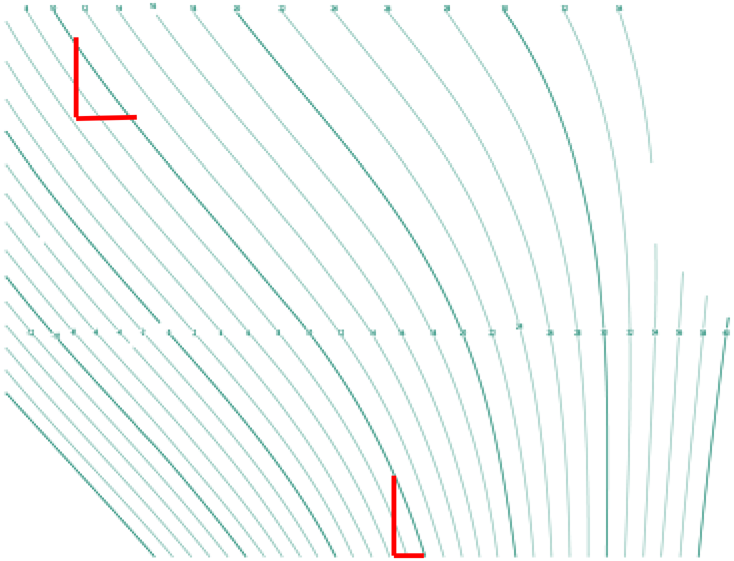


http://www.srh.noaa.gov/jetstream/

Skew T – Log P Diagram

Moist (or Saturated) Adiabats

- Near the surface, as saturated air rises, it expands and begins to cool at a rate of about 4°C/km.
- As it continues to rise, the cooling rate decreases due to a decreasing amount of water vapor.
- On the Skew T the dry and wet adiabats become nearly parallel in the upper troposphere where the rate of cooling approaches that of dry adiabats, ~9.8°C/km.
- These are also called pseudoadiabats and are lines of constant equivalent potential temperature (θ_e)



http://www.srh.noaa.gov/jetstream/

Skew T – Log P Diagram

Mixing Ratio (g/kg)

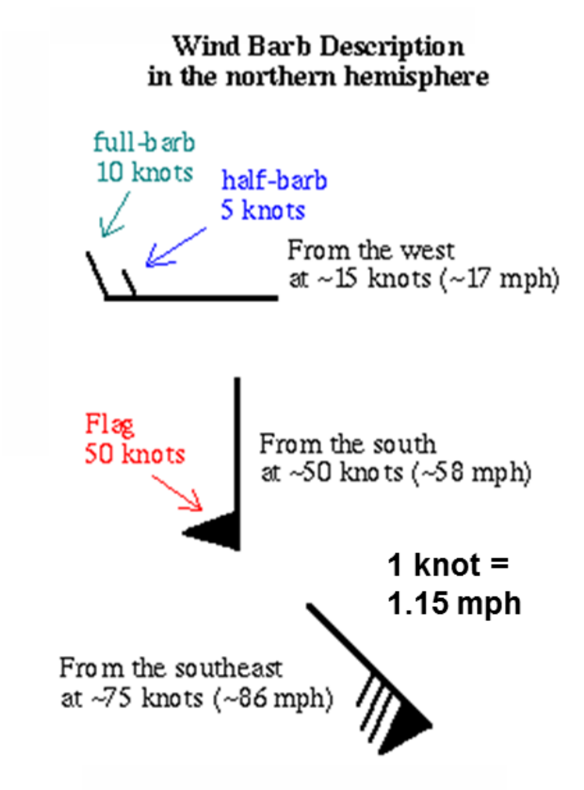
- Mixing ratio is the mass of water vapor compared with the mass of dry air.
- On a plotted radiosonde sounding, the mixing ratio at any given level is the amount of water vapor in the air where the dew point temperature line crosses the mixing ratio line.
- The saturation mixing ratio is the maximum amount of water vapor that can be in the air at any given level and is found where the temperature line crosses the mixing ratio line.

http://www.srh.noaa.gov/jetstream/

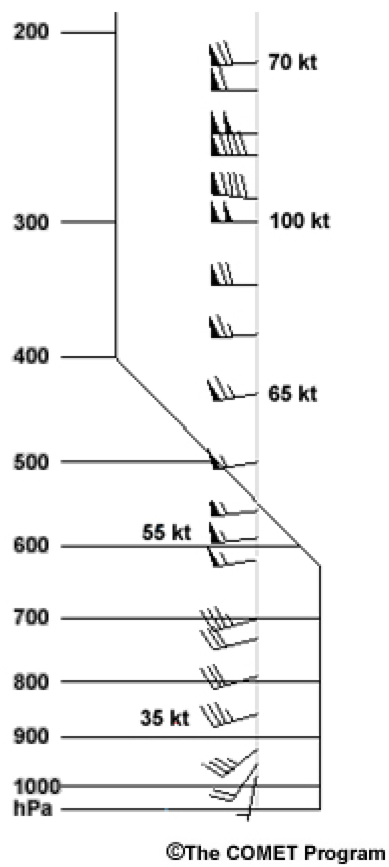
Skew T – Log P Diagram

Wind Staff

- These staffs are for plotting the wind speed and direction as observed by the radiosonde.



1 knot = 1.15 mph



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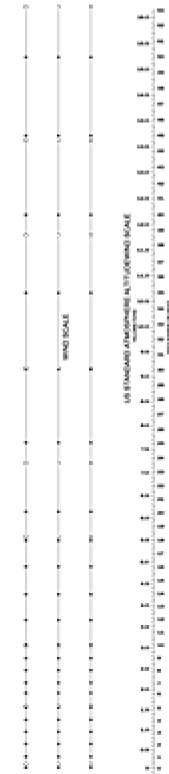

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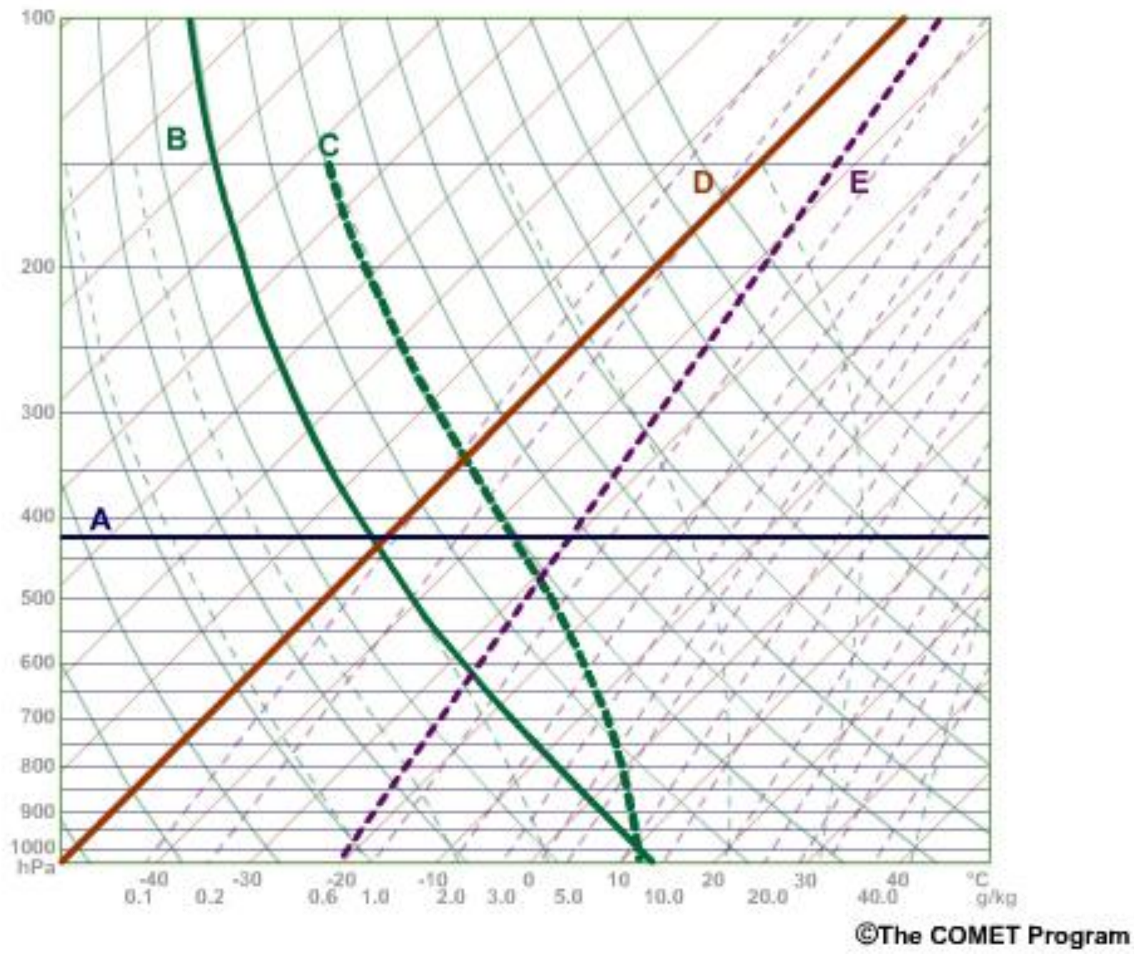
Skew T – Log P Diagram

Can you name the lines?



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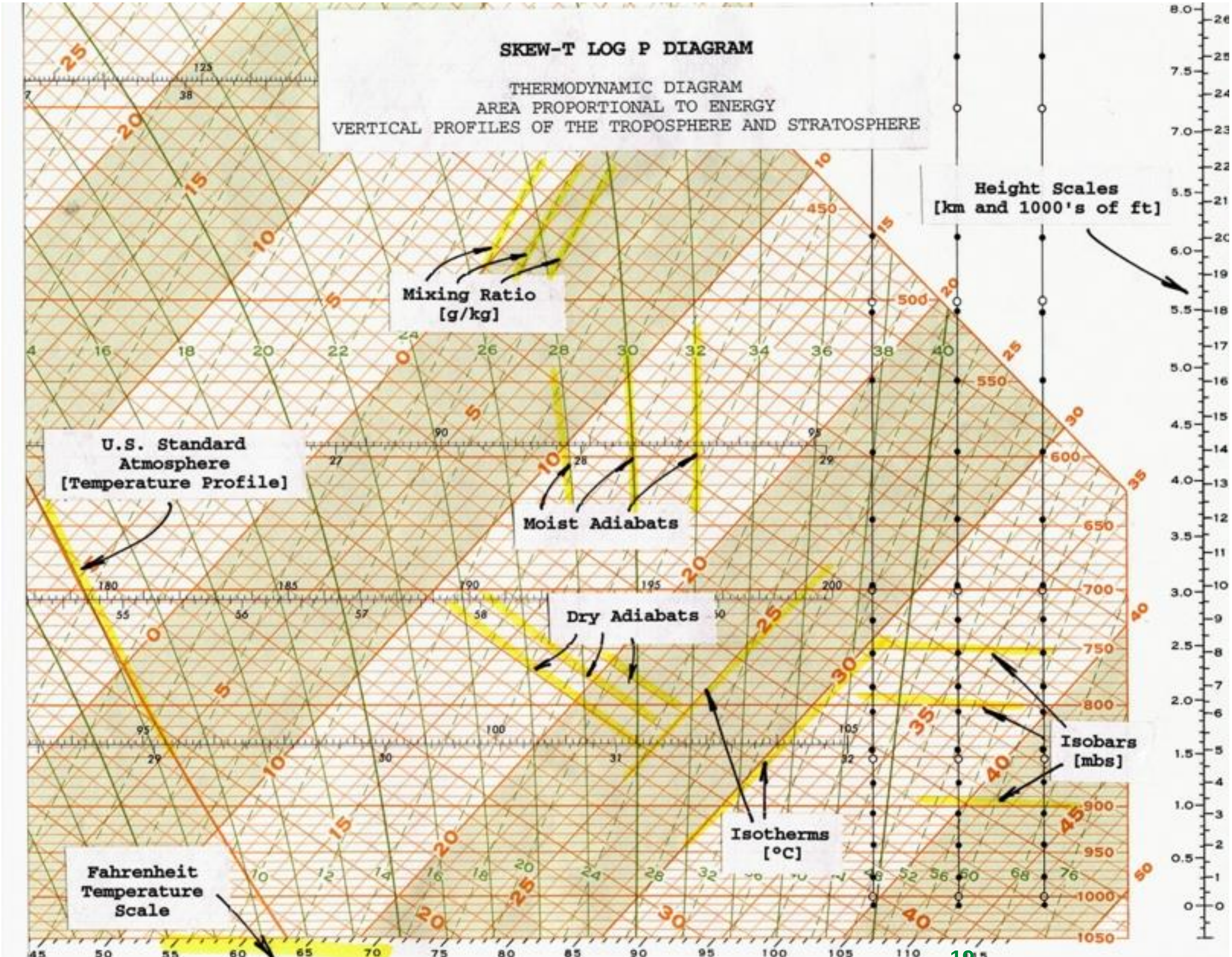
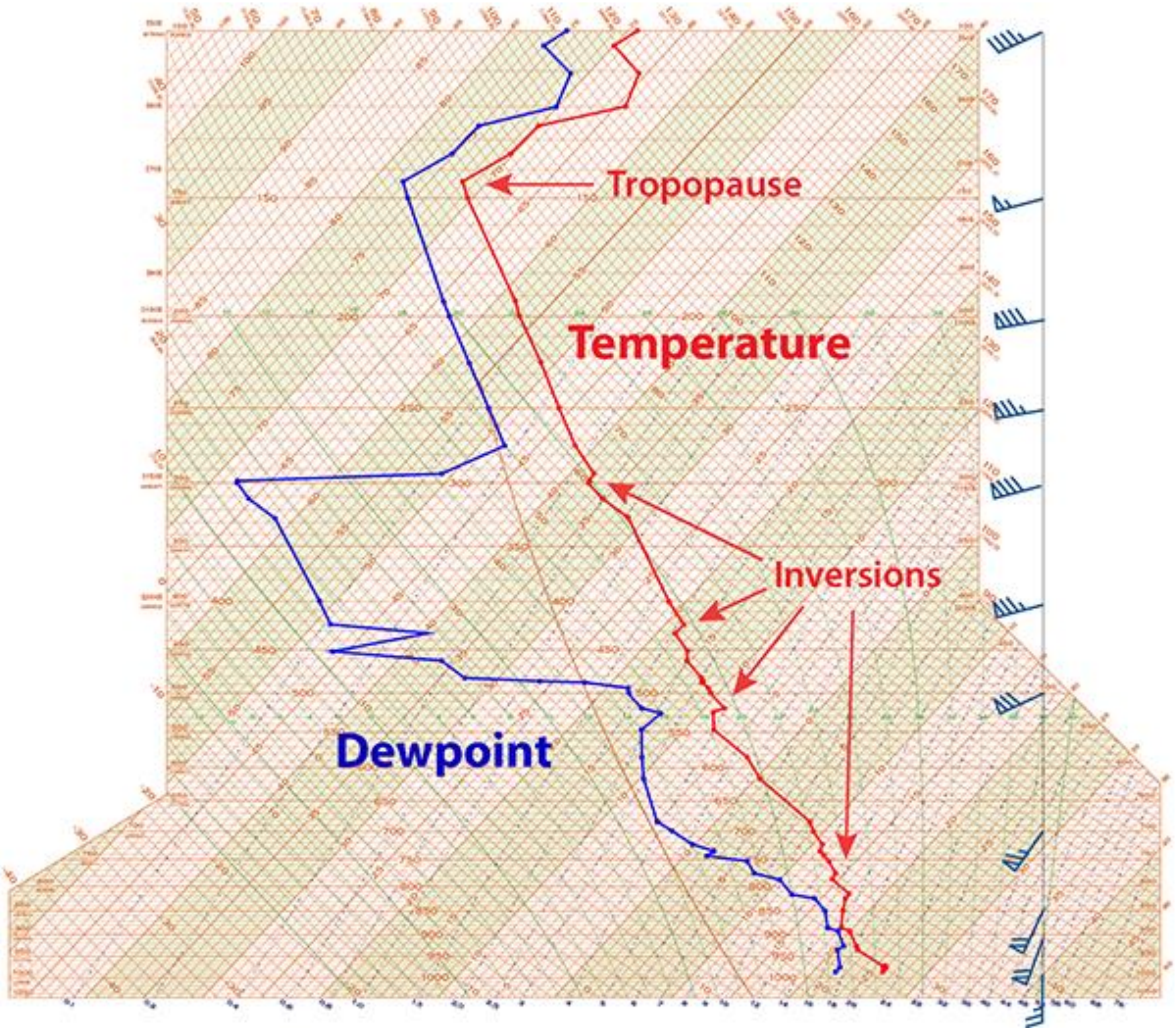


http://pielkeclimatesci.wordpress.com/

Skew T – Log P Diagram



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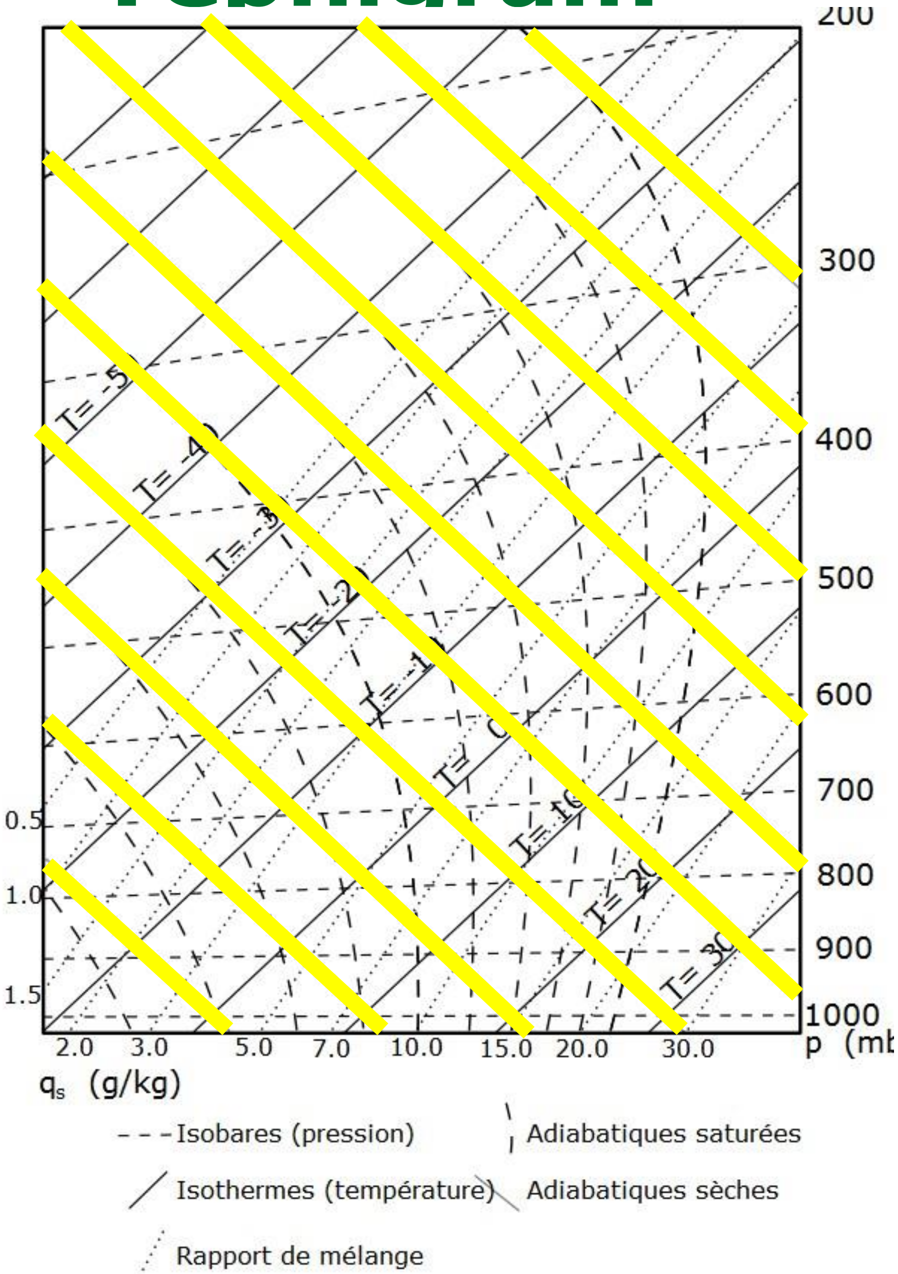
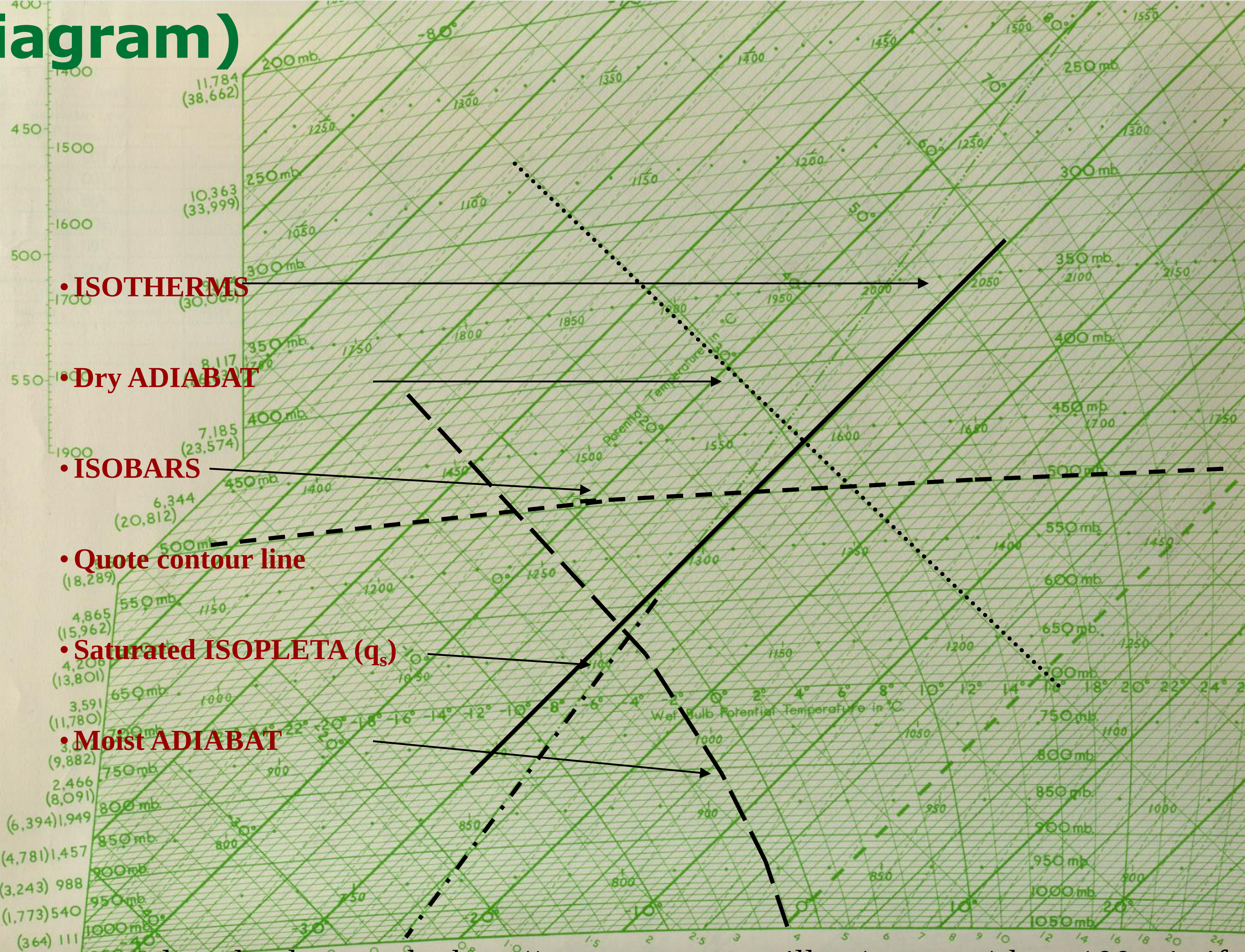
Tephigram



- From the words T-phi-gram, indicating that isotherms and isentropics are plotted
- Diagram which reports the main characteristic thermodynamic variables:
  - Isobars (which are almost horizontal and have a slight curve)
  - Isotherms (straights at 45° to the right)
  - Dry adiabats (straights at 45° to the left)
  - Moist adiabats
  - Saturation mixing ratio (or specific humidity)
- Used by Met Office
- Property: areas contained by the curves have equal energies for equal areas
  - Quite good for considerations about CAPE and convection

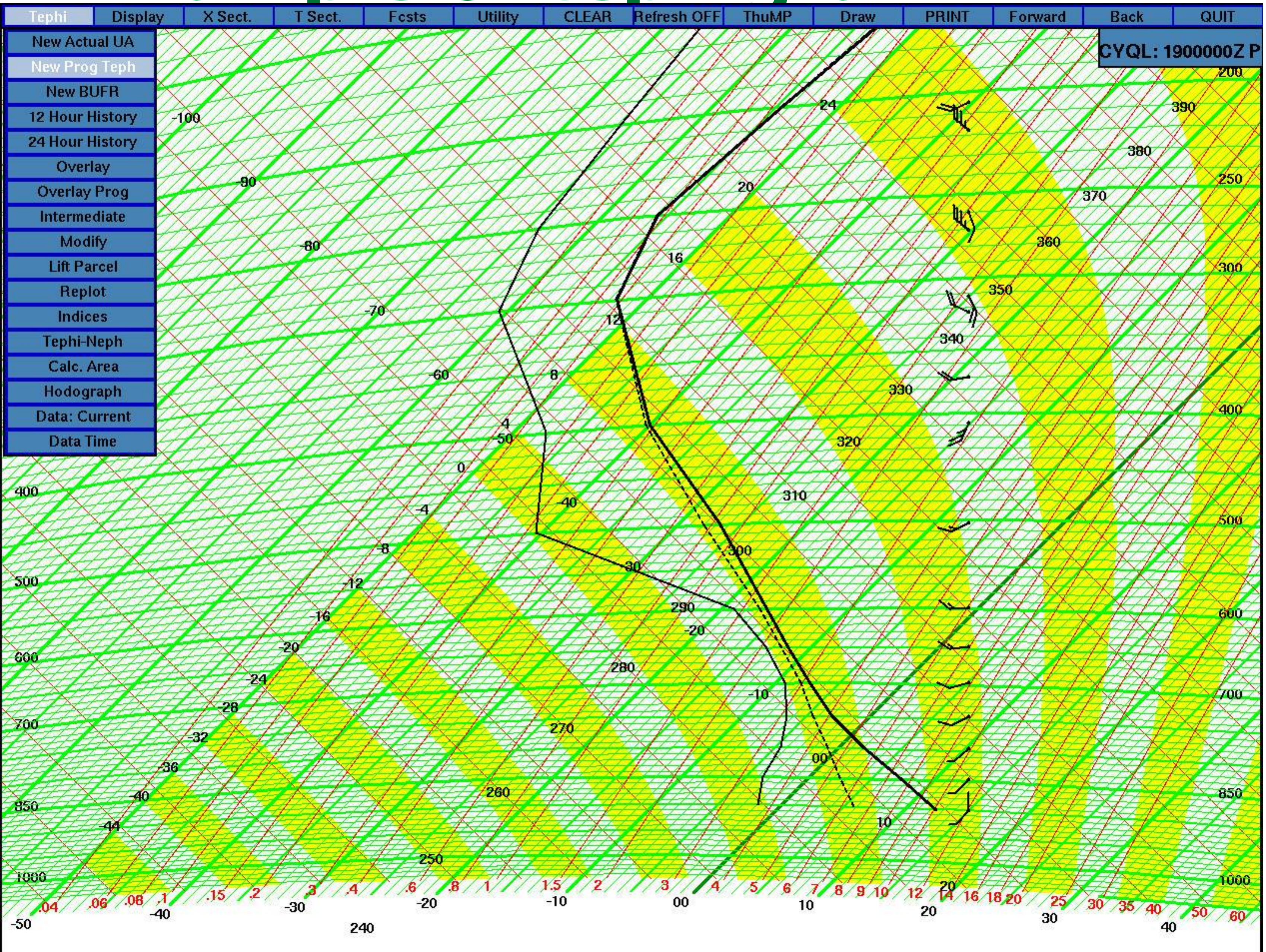
diagram)



- ISOTHERMS
- Dry ADIABAT
- ISOBARS
- Quote contour line
- Saturated ISOPLETA (q_s)
- Moist ADIABAT

Here you can download a sample: http://www.meteo.mcgill.ca/extreme/chart-100ppi.gif

Example of tephigram



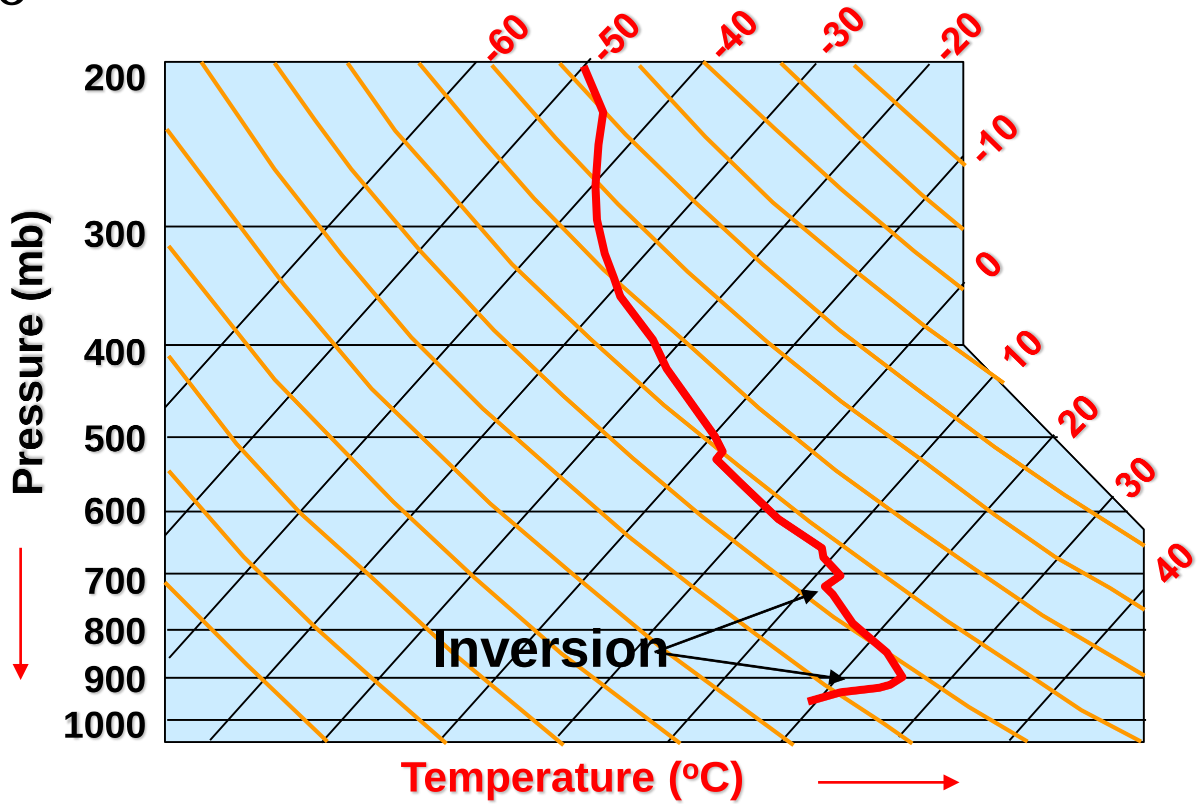
Temperature Inversion

Increase in temperature with height:

$$\frac{dT}{dz} > 0$$

Types of inversion

- Radiation
- Frontal
- Subsidence
- Turbulent

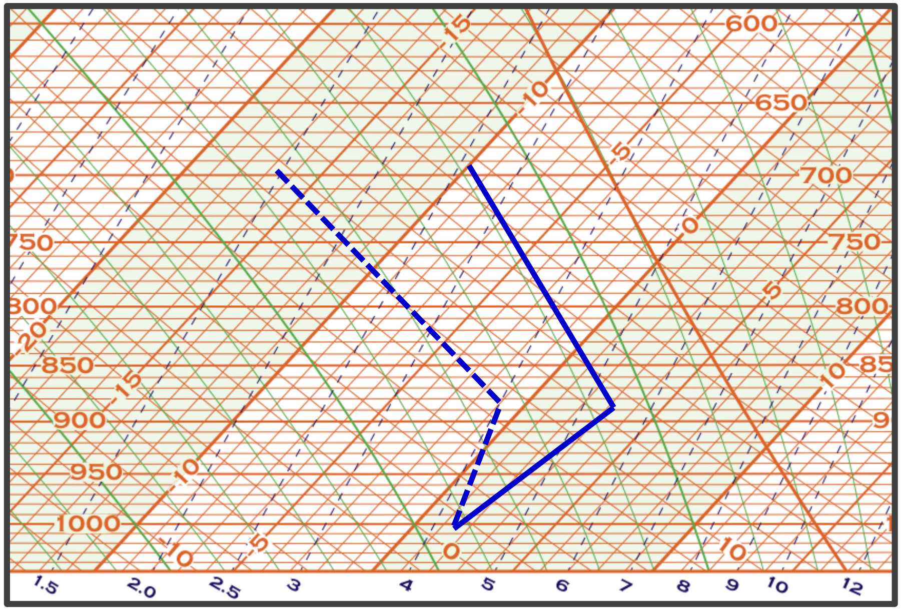


(courtesy F. Remer)

Temperature Inversion

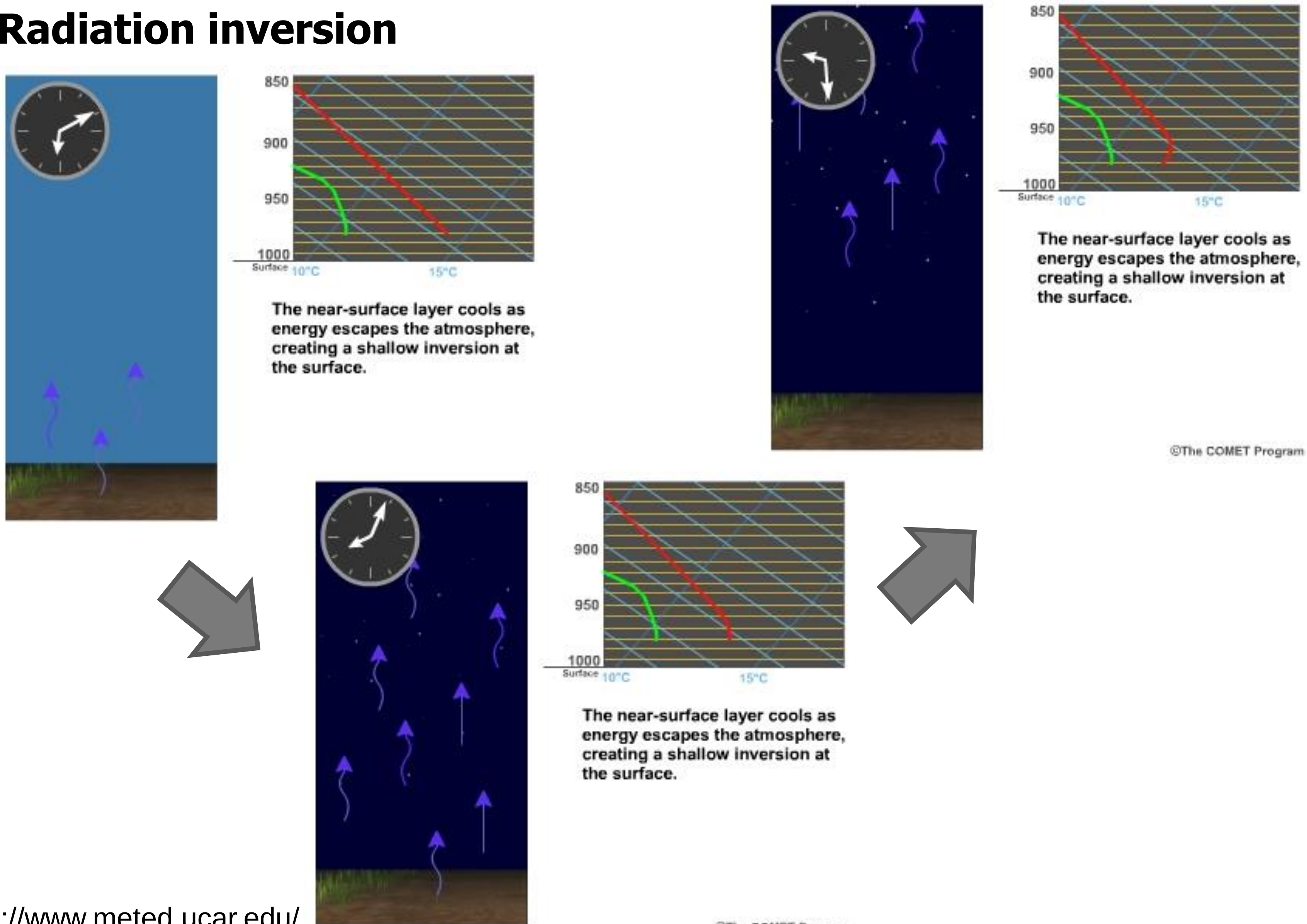
Radiation inversion

- Caused by surface cooling during calm, cool, stable conditions.
- Surface based.
- Often $T = T_d$ at surface.
- T_d is almost parallel to mixing ratio in inversion.
- T and T_d cool above the inversion.



Temperature Inversion

Radiation inversion

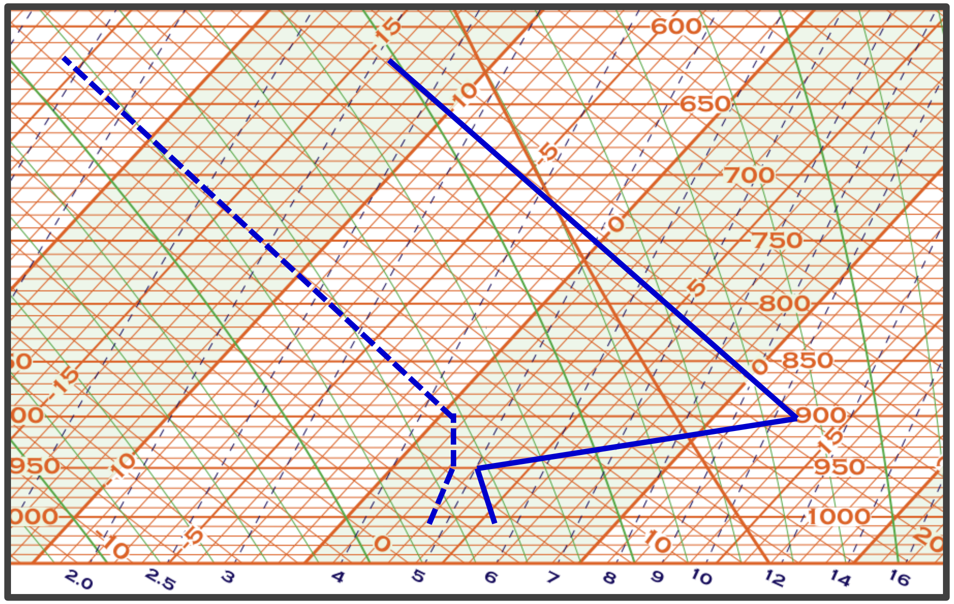


https://www.meted.ucar.edu/

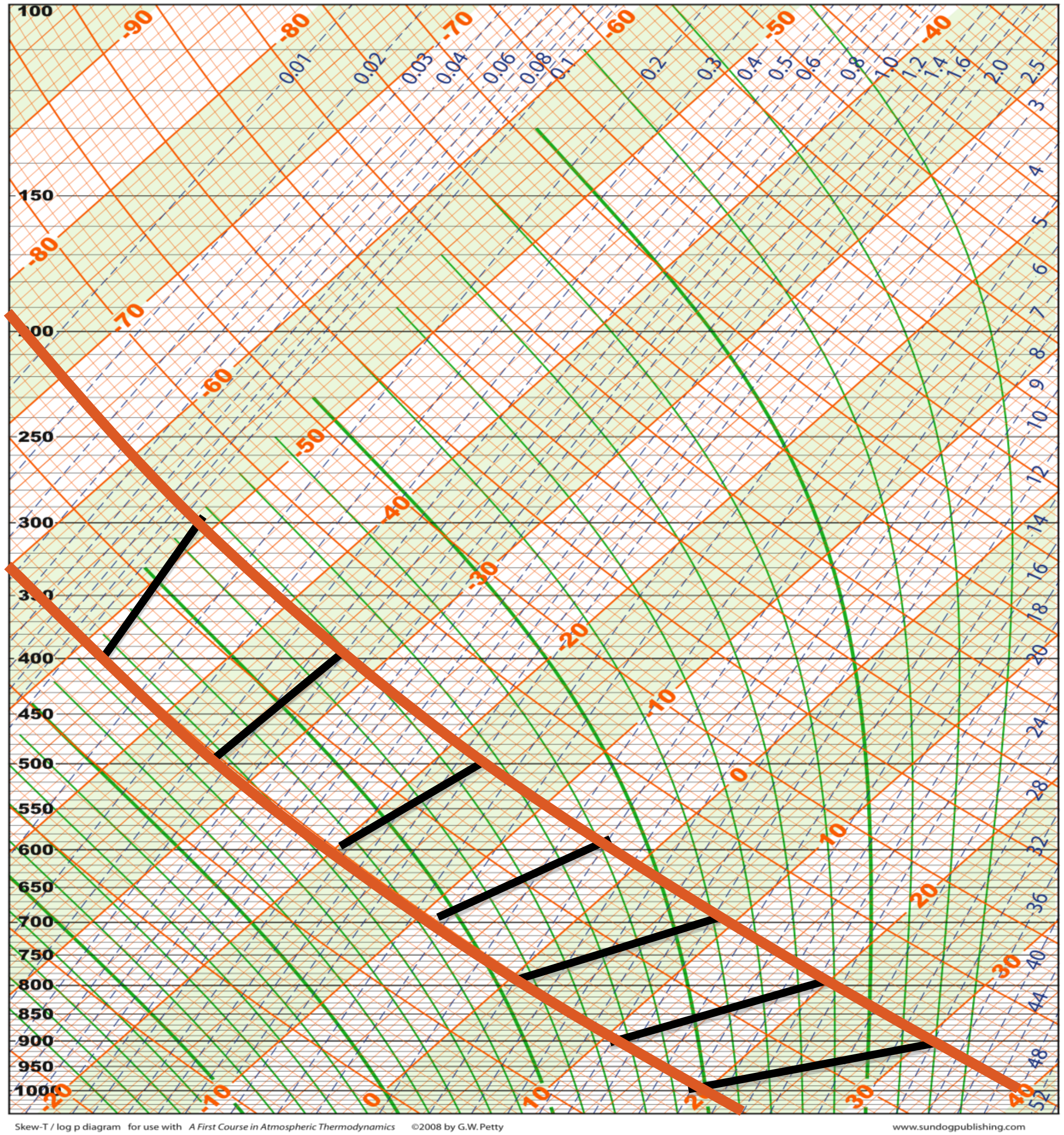
Temperature Inversion

Subsidence inversion

- Caused by settling currents beneath high pressure cell, especially subtropical ridge.
- T increases in inversion.
- T_d rapidly decreases in inversion.
- T cools nearly dry-adiabatically above inversion.



Temperature Inversion



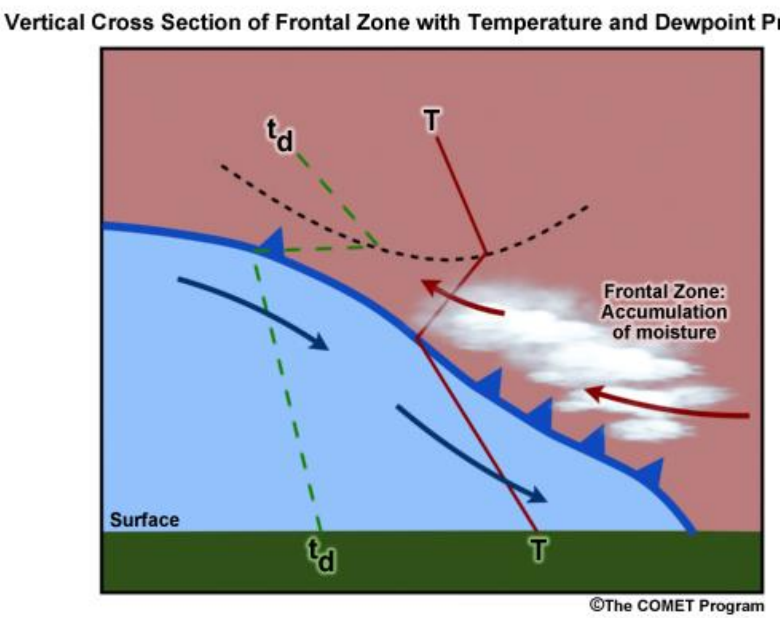
Subsidence inversion:

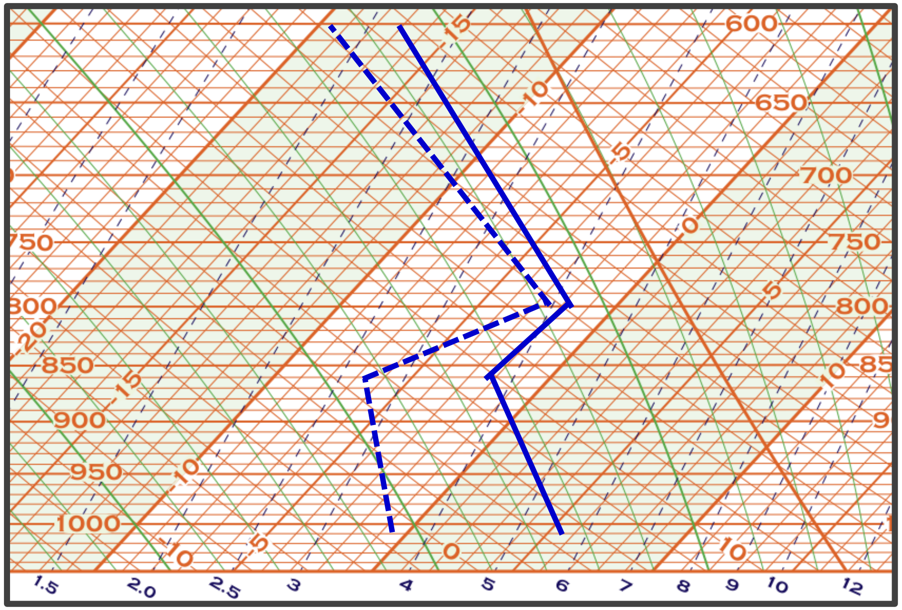
- Suppose air from 200 – 300hPa layer is subsiding adiabatically.
- 300-200hPa: Lapse rate < 0
- 500 hPa: Close to isothermal
- Below 500hPa: Stronger and stronger inversions
- 1000-900hPa: almost 10ºC warmer above

Temperature Inversion

Frontal inversion

- Transition zone between two air masses rotated into horizontal plane.
- T shallow isothermal or stable in inversion.
- T_d increases within inversion.



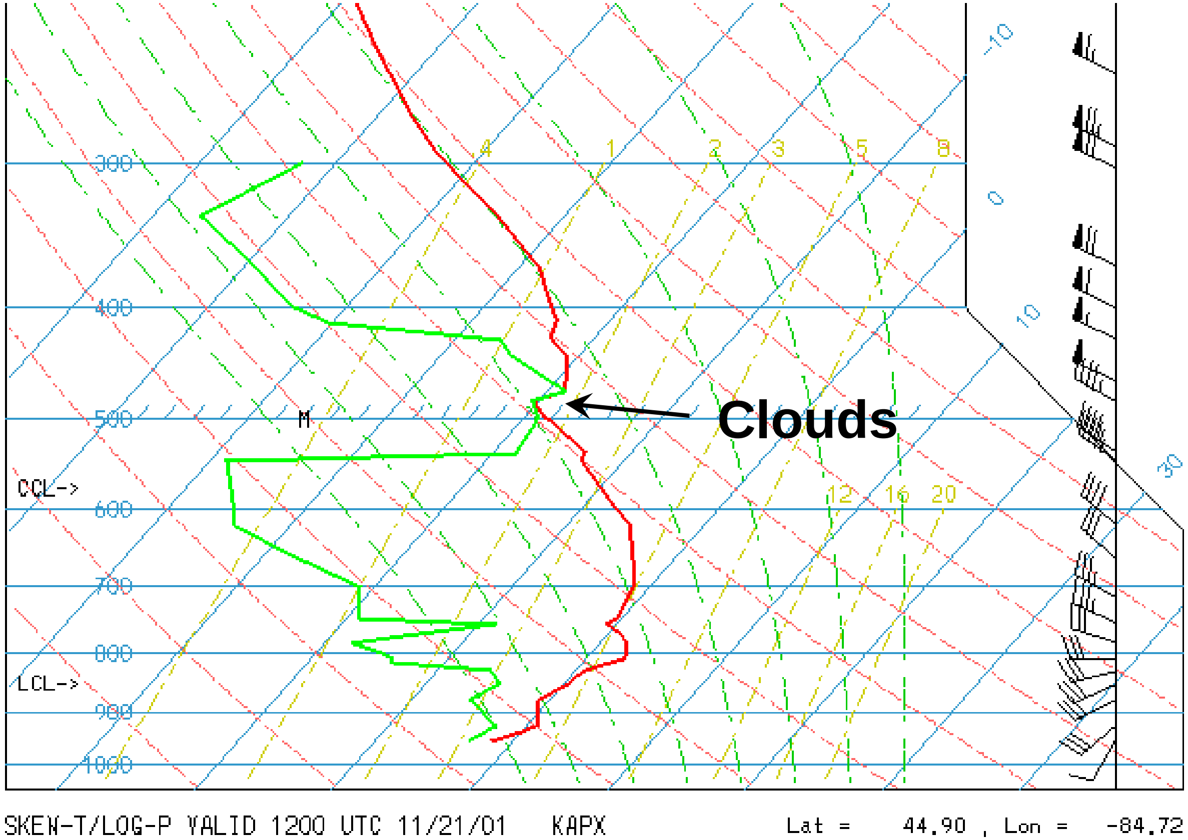


https://www.meted.ucar.edu/

Cloud

Cloud in thermodynamic diagram

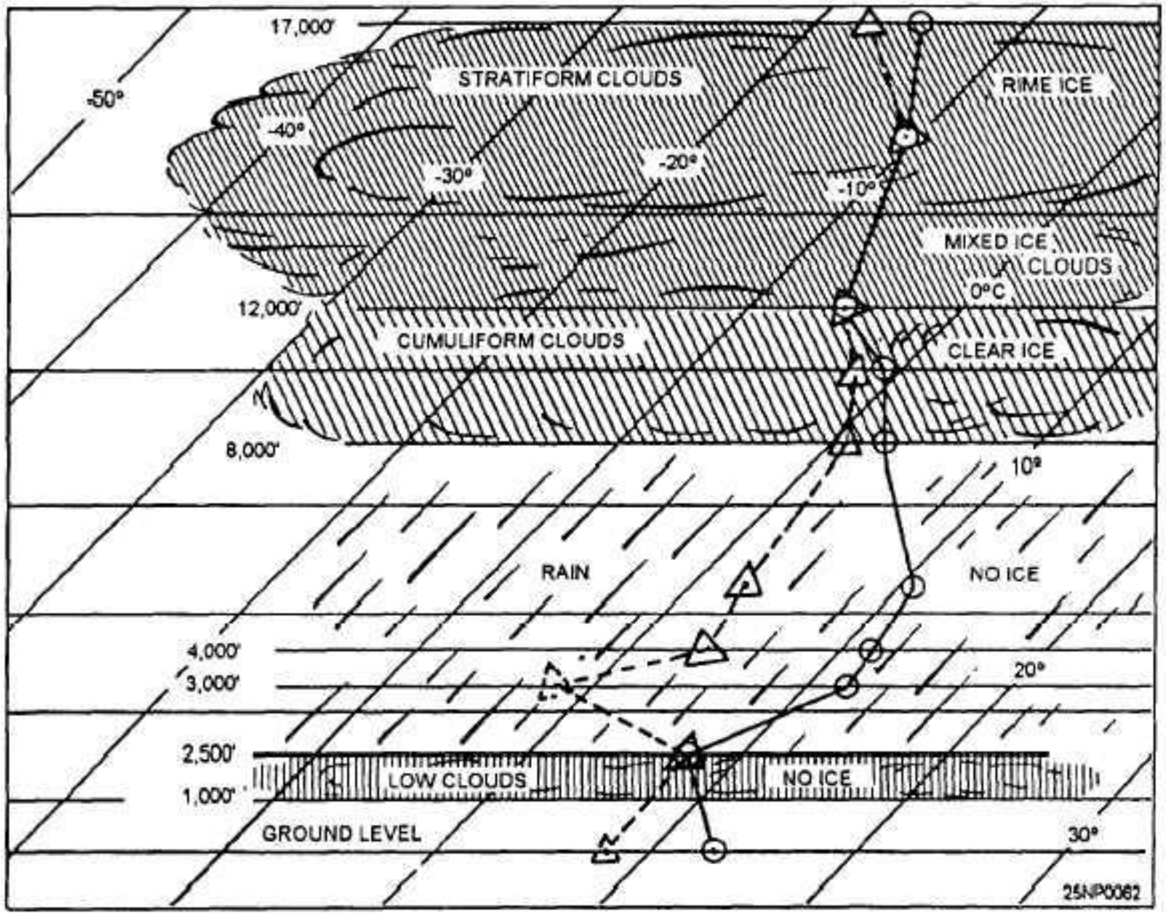
- Usually occurs when $T - T_d < 5°C$.



(courtesy F. Remer)

Cloud

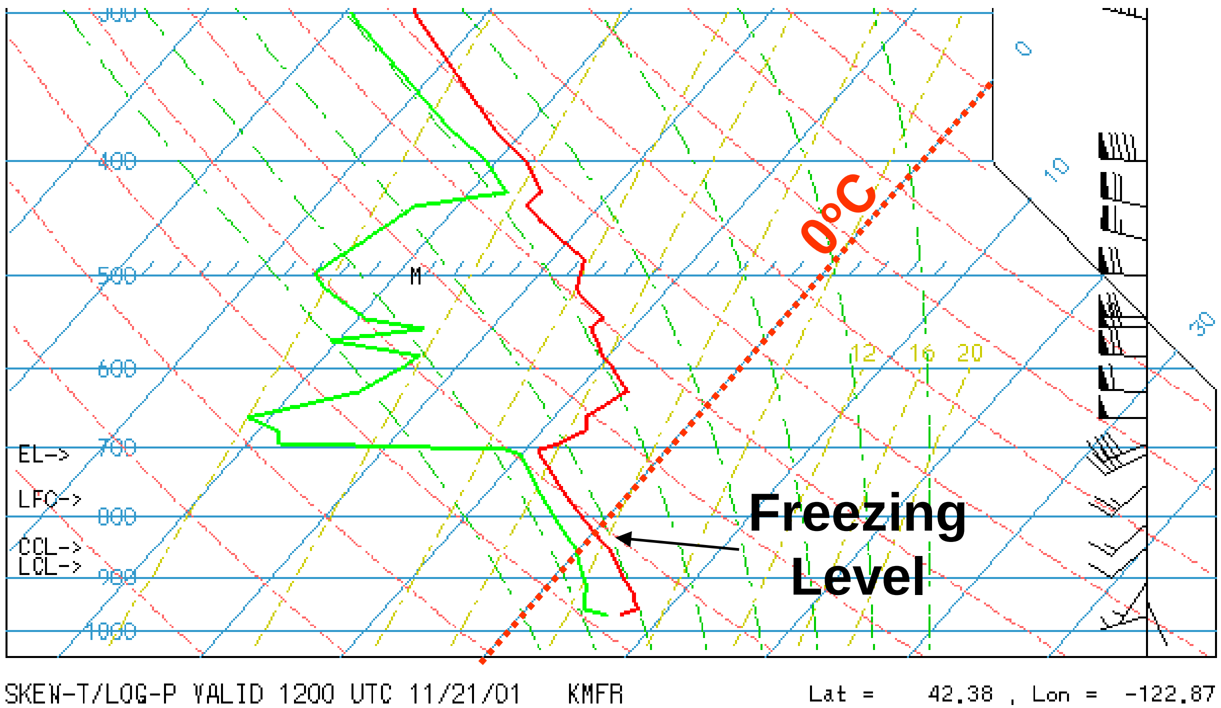
Clouds in thermodynamic diagram



http://www.tpub.com/

Freezing Level (FL)

Height at which 0°C occurs in the atmosphere.



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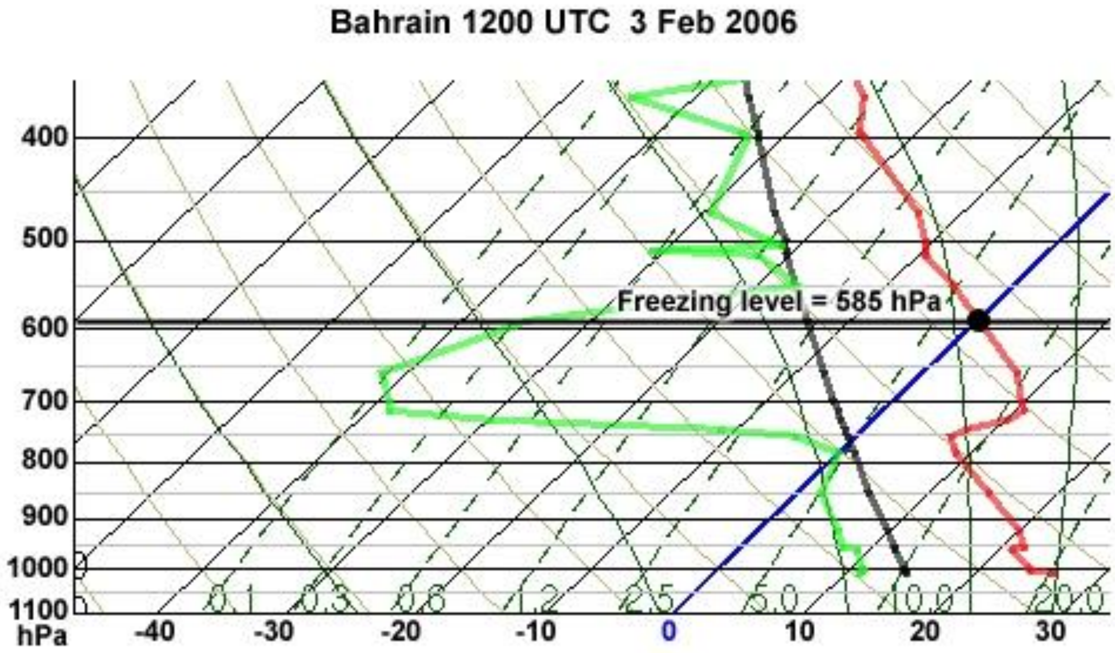

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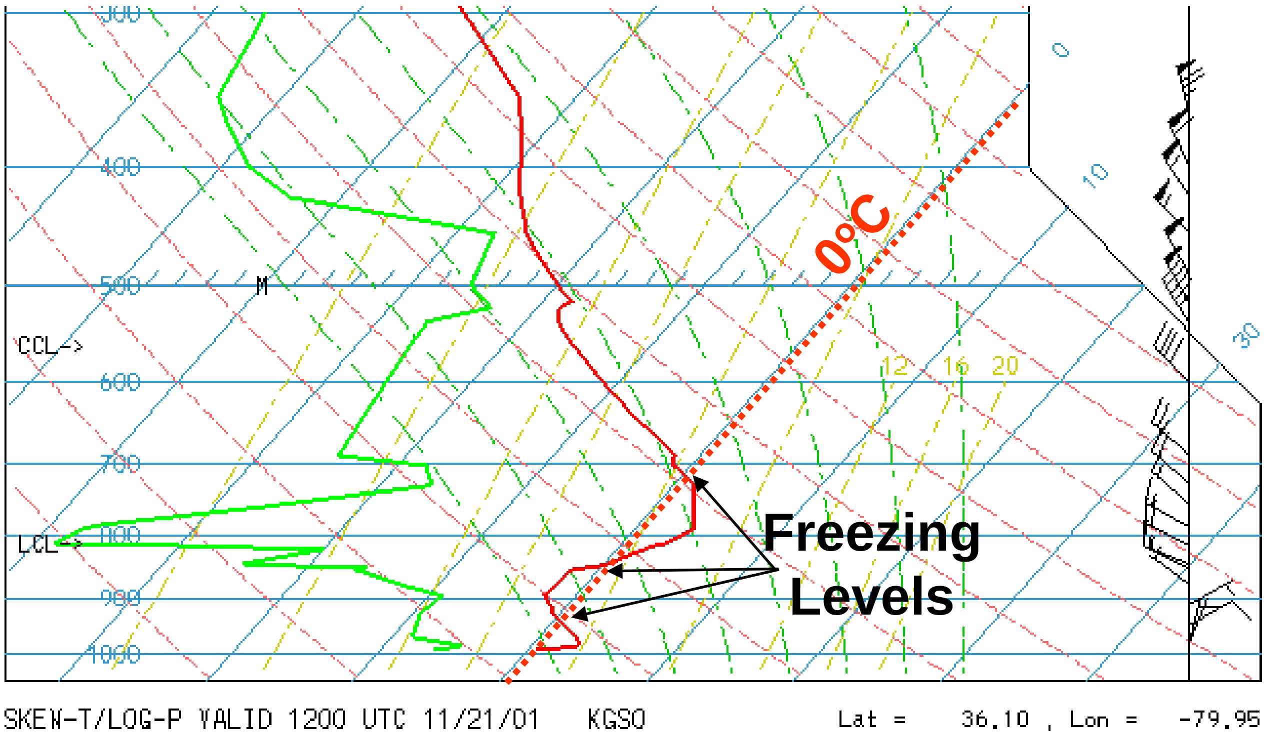
Freezing Level (FL)

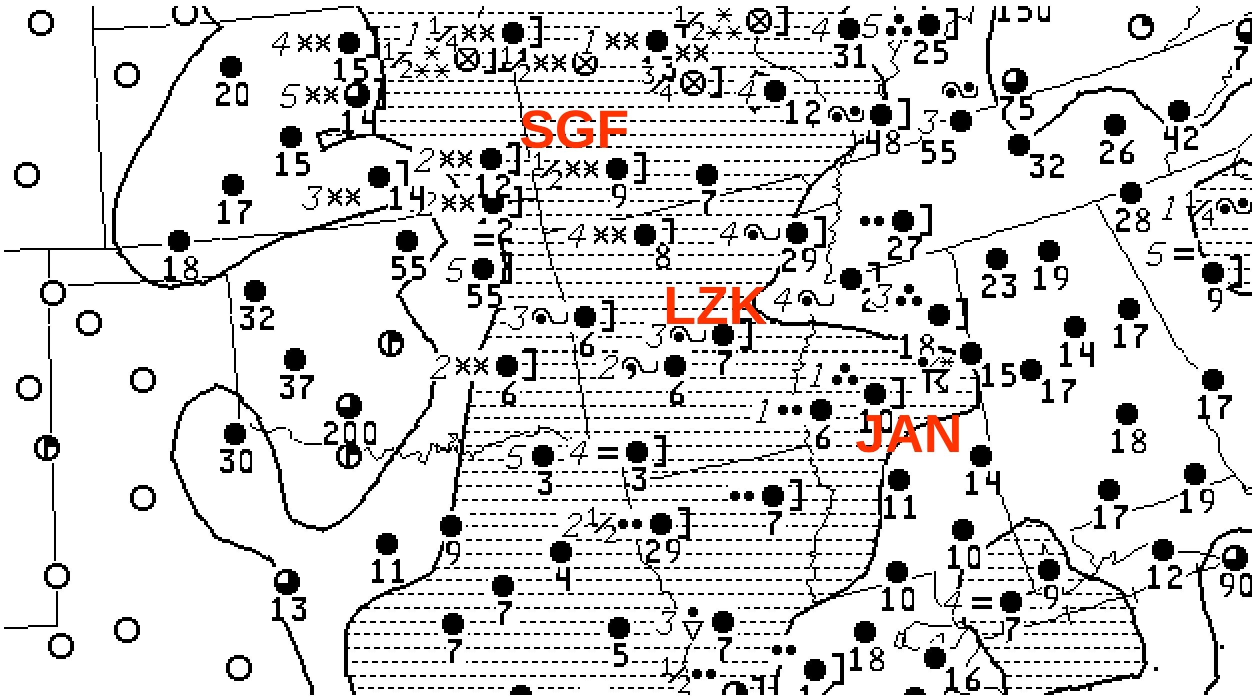
Multiple Freezing Levels



(courtesy F. Remer)

Freezing Level (FL)

FL is important in forecasting precipitation type.



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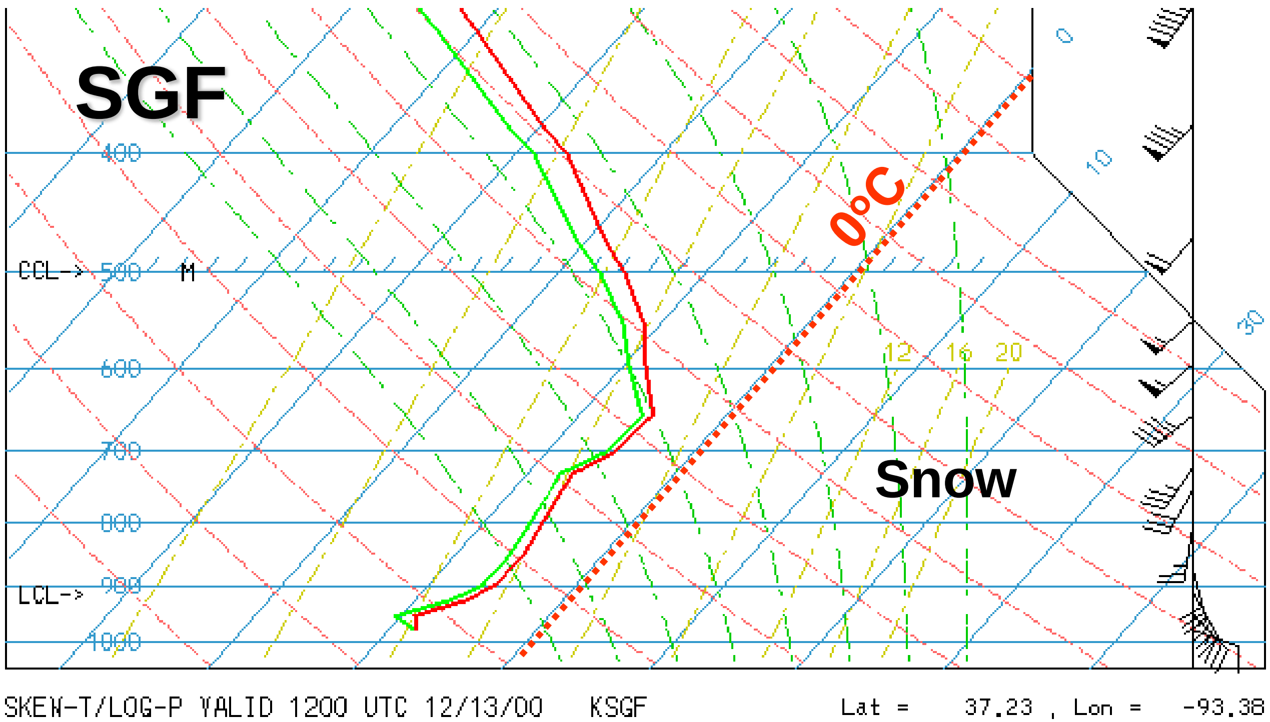

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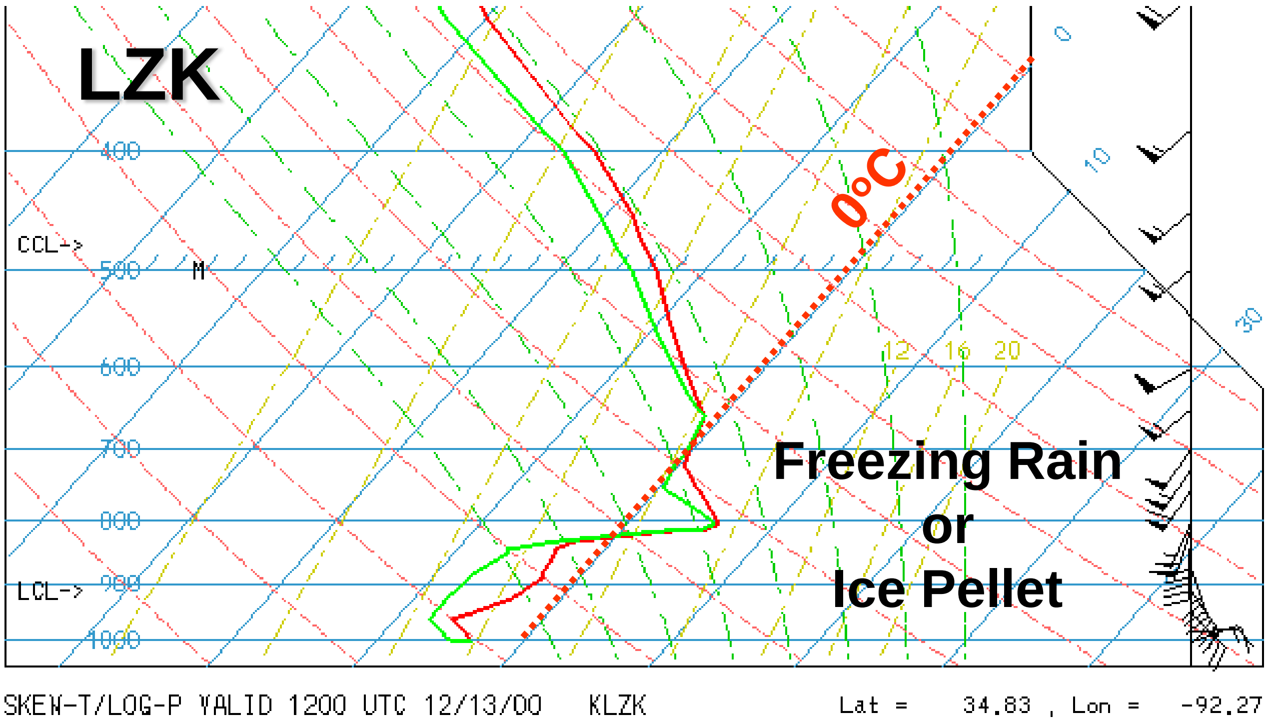

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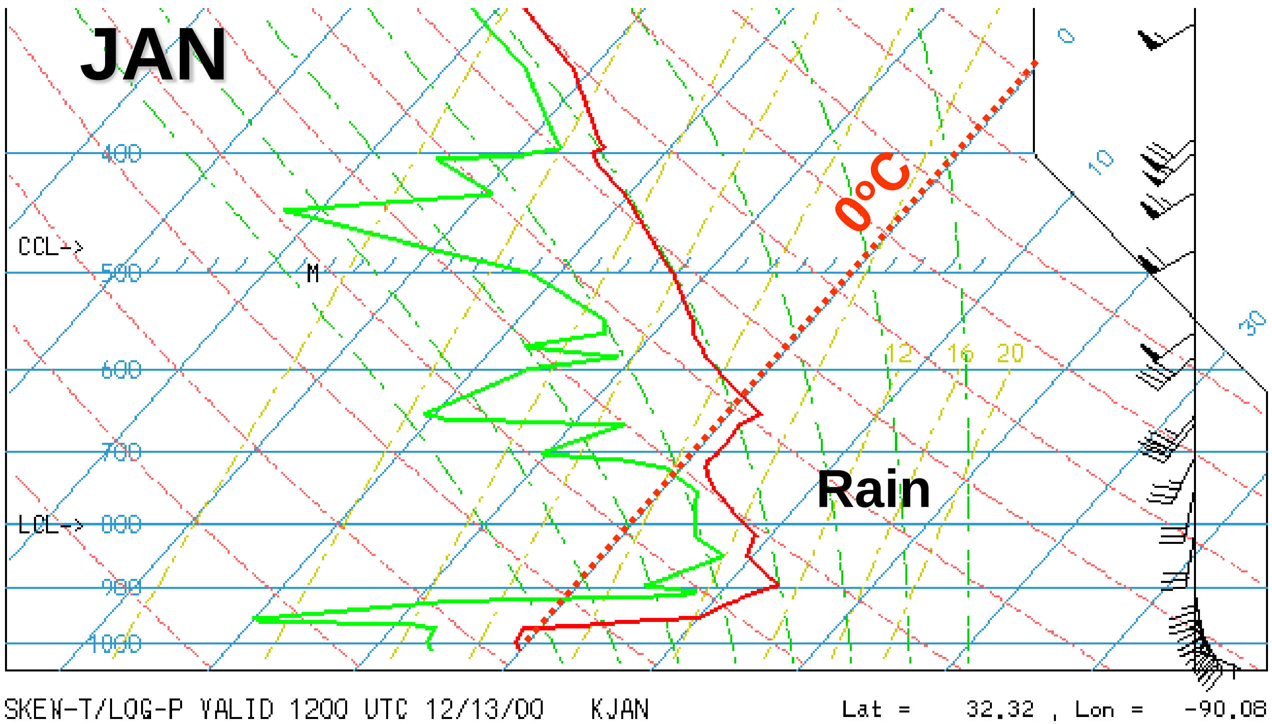


(courtesy F. Remer)

Tropopause

Troposphere

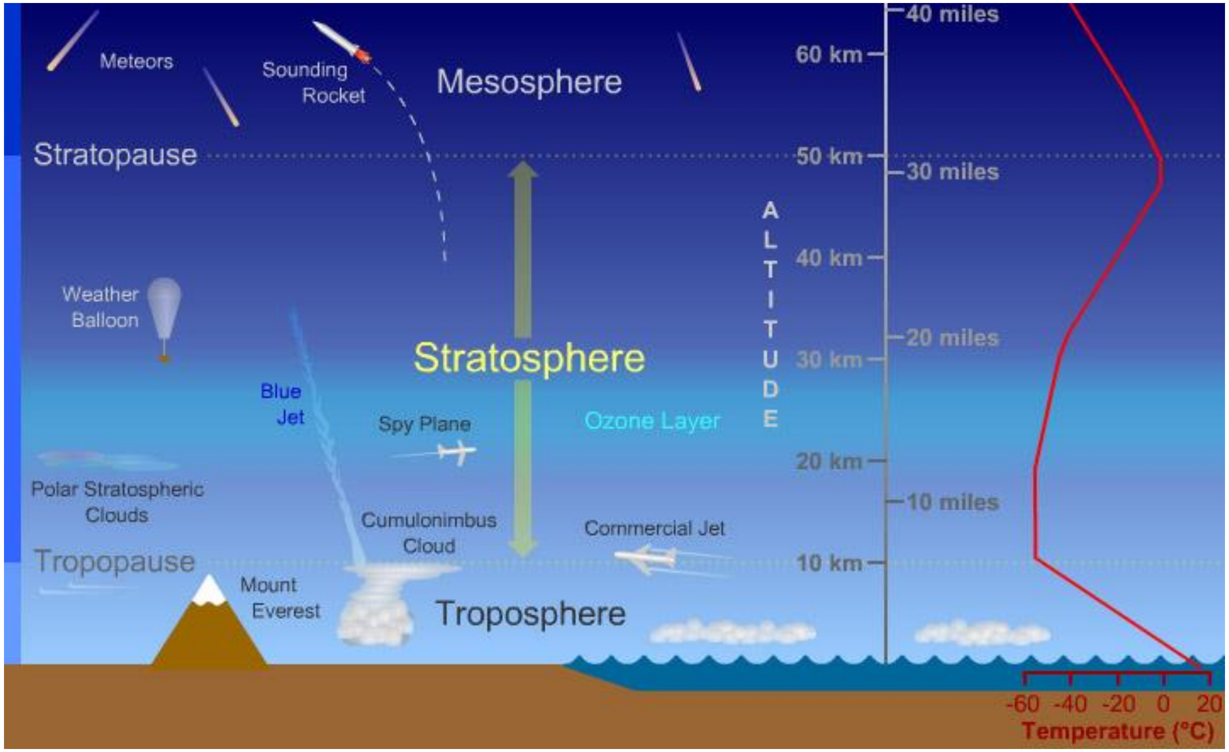
- Temperature decreases with height.

Stratosphere

- Temperature increases with height.

Tropopause

- Top of troposphere where the lapse rate decreases to 2ºC/km or less.



http://scied.ucar.edu/

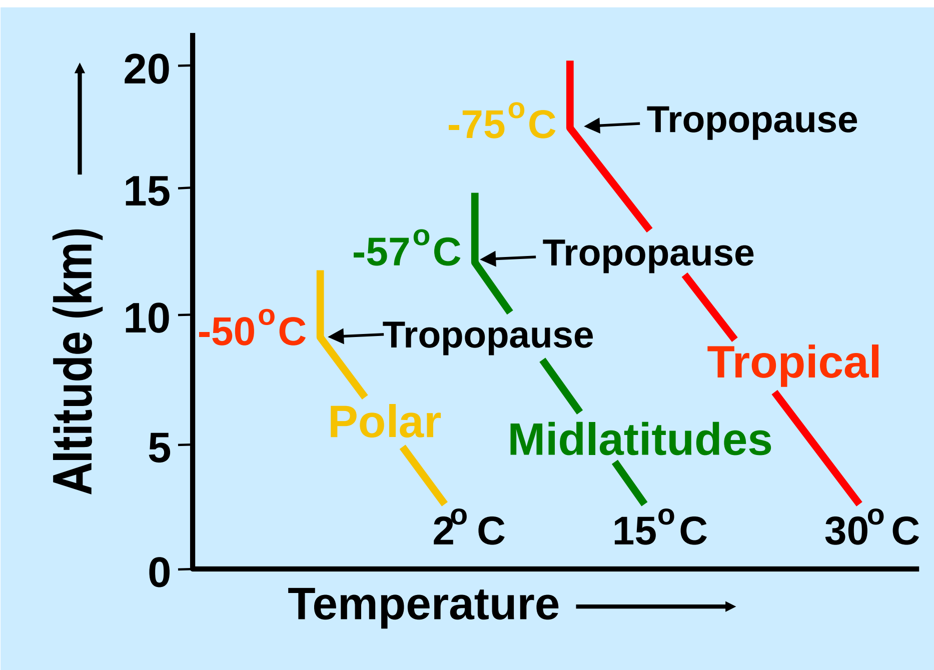
Tropopause

Tropopause Height

- Lower at Poles
- Higher at Equator

Tropopause Temperature

- Warmer at Poles
- Colder at Equator



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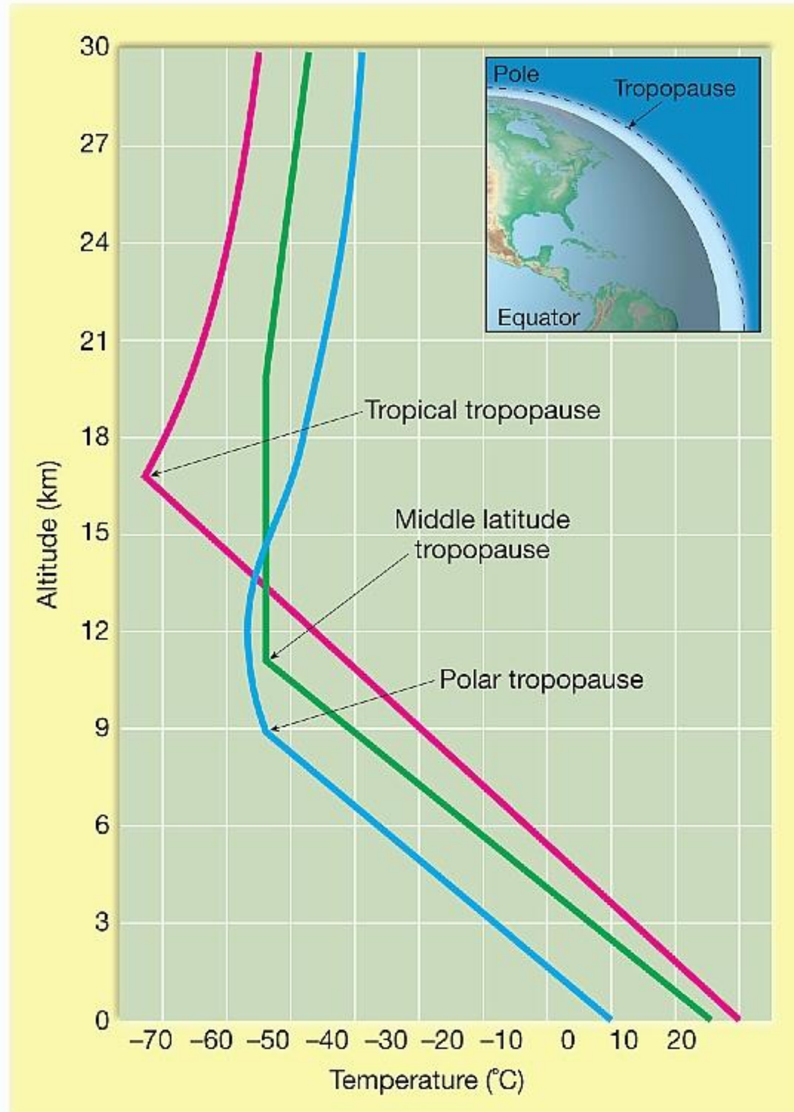
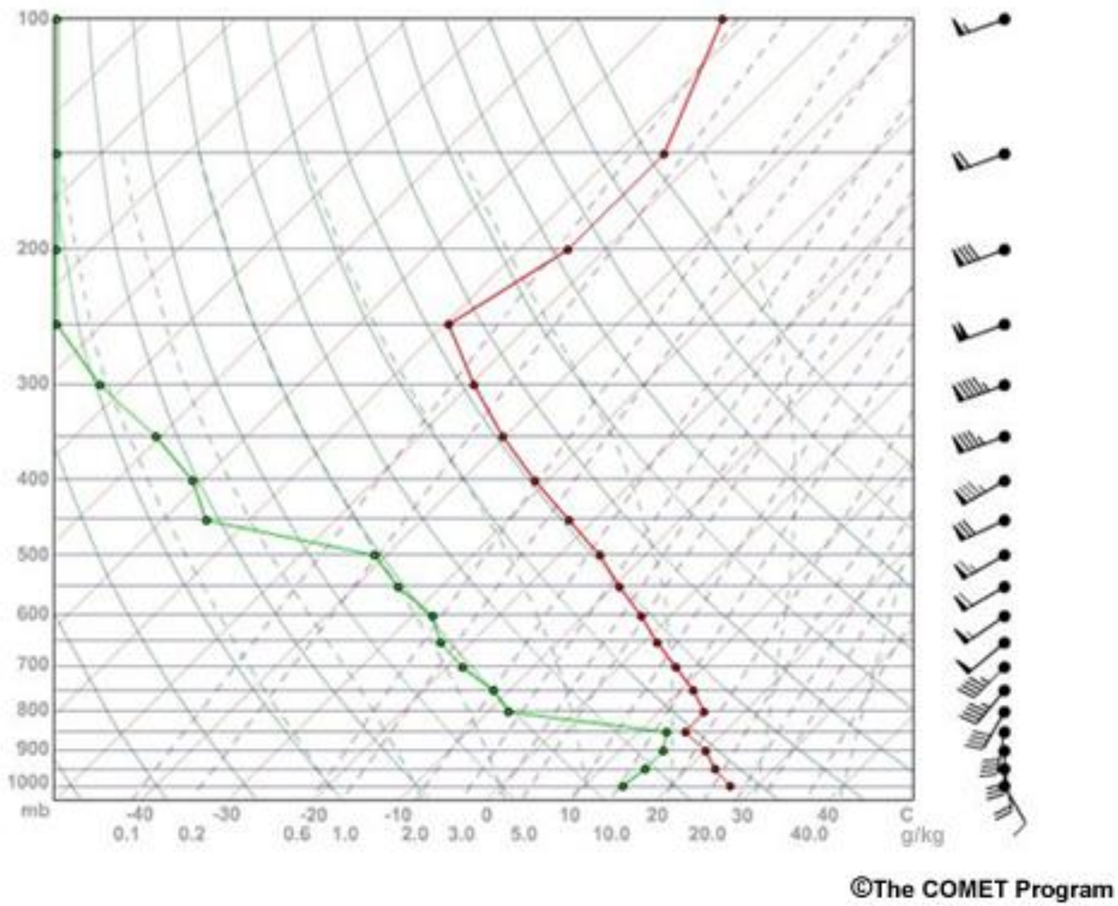


Tropopause

Where is tropopause (T/P)?



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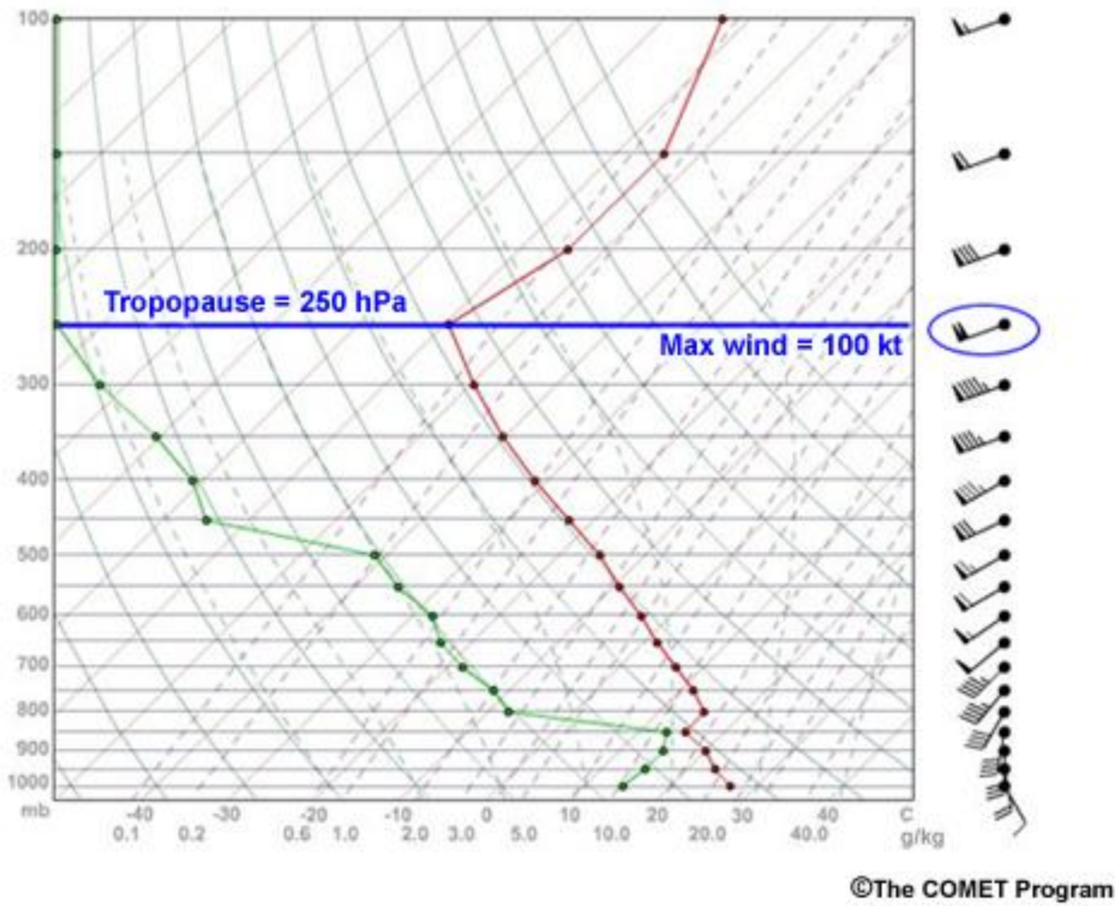

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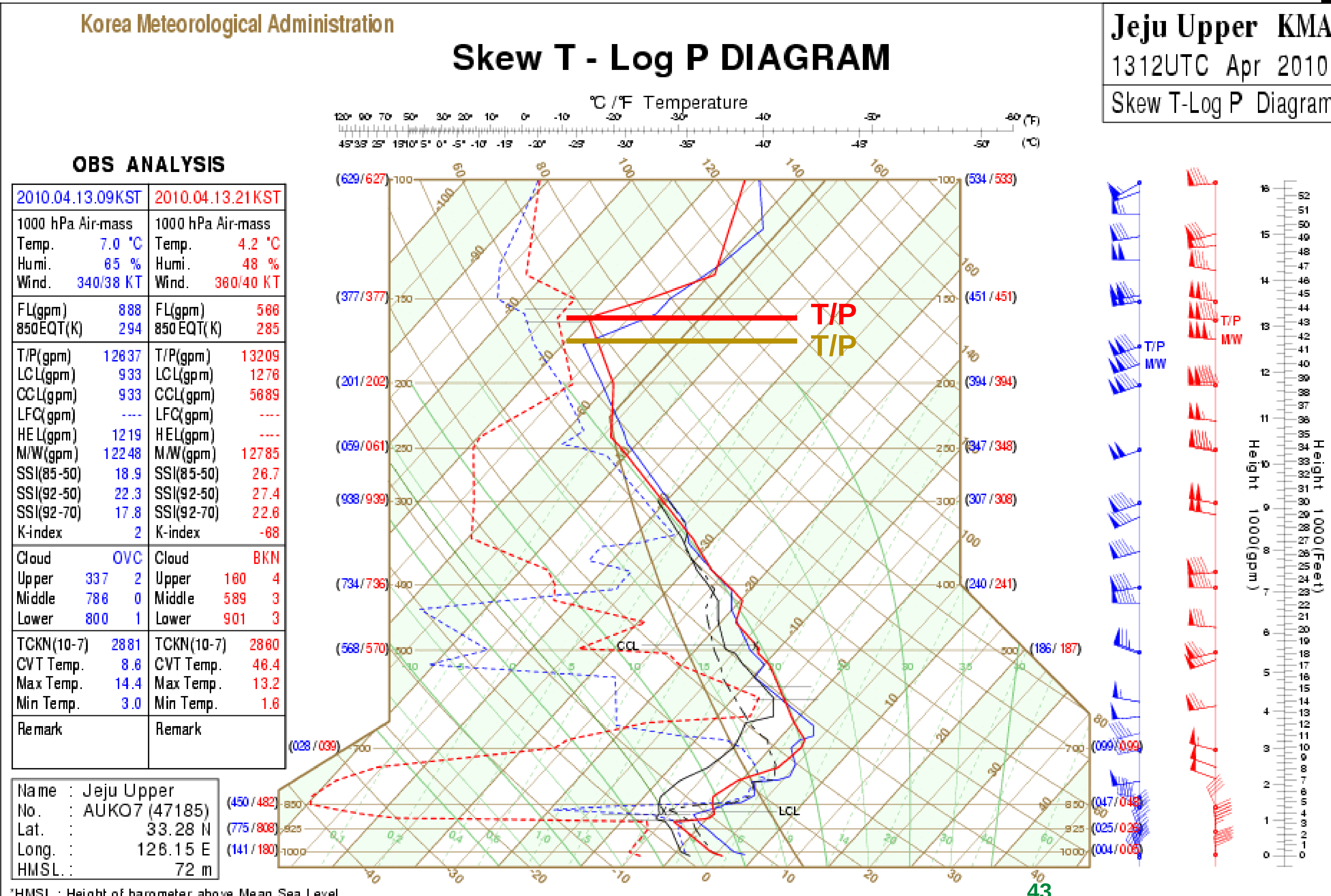
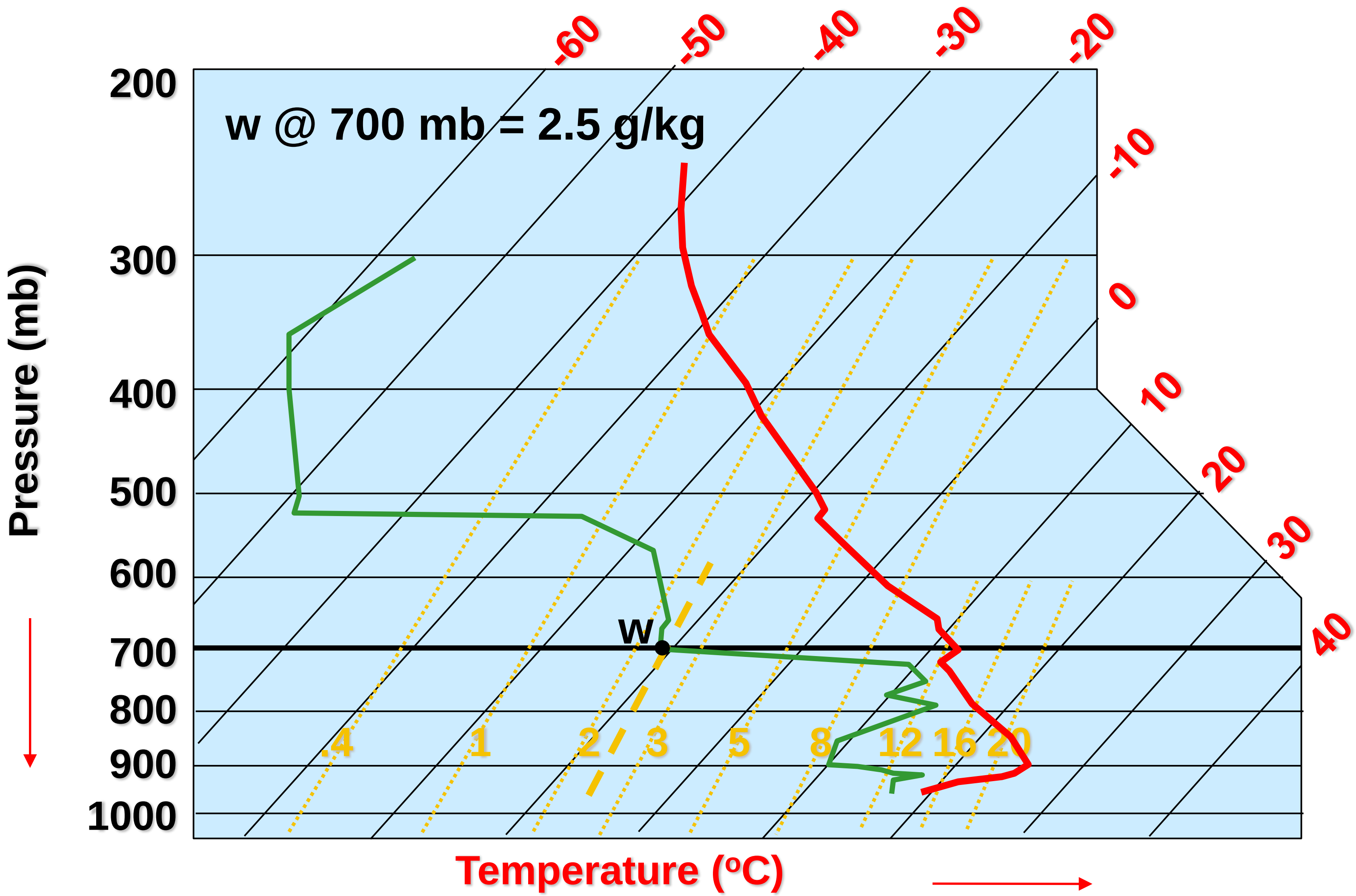
Tropopause



2010.04.13.09KST		2010.04.13.21KST	
1000 hPa Air-mass		1000 hPa Air-mass	
Temp.	7.0 ℃	Temp.	4.2 ℃
Humi.	65 %	Humi.	48 %
Wind.	340/38 KT	Wind.	360/40 KT
FL(gpm)	888	FL(gpm)	566
850EQT(K)	294	850EQT(K)	285
T/P(gpm)	12637	T/P(gpm)	13209
LCL(gpm)	933	LCL(gpm)	1276
CCL(gpm)	933	CCL(gpm)	5689
LFC(gpm)	----	LFC(gpm)	----
HEL(gpm)	1219	HEL(gpm)	----
M/W(gpm)	12248	M/W(gpm)	12785
SSI(85-50)	18.9	SSI(85-50)	26.7
SSI(92-50)	22.3	SSI(92-50)	27.4
SSI(92-70)	17.8	SSI(92-70)	22.6
K-index	2	K-index	-68
Cloud	OVC	Cloud	BKN
Upper	337 2	Upper	160 4
Middle	786 0	Middle	589 3
Lower	800 1	Lower	901 3
TCKN(10-7)	2881	TCKN(10-7)	2860
CVT Temp.	8.6	CVT Temp.	46.4
Max Temp.	14.4	Max Temp.	13.2
Min Temp.	3.0	Min Temp.	1.6
Remark		Remark	

Moist & Thermodynamic Variables

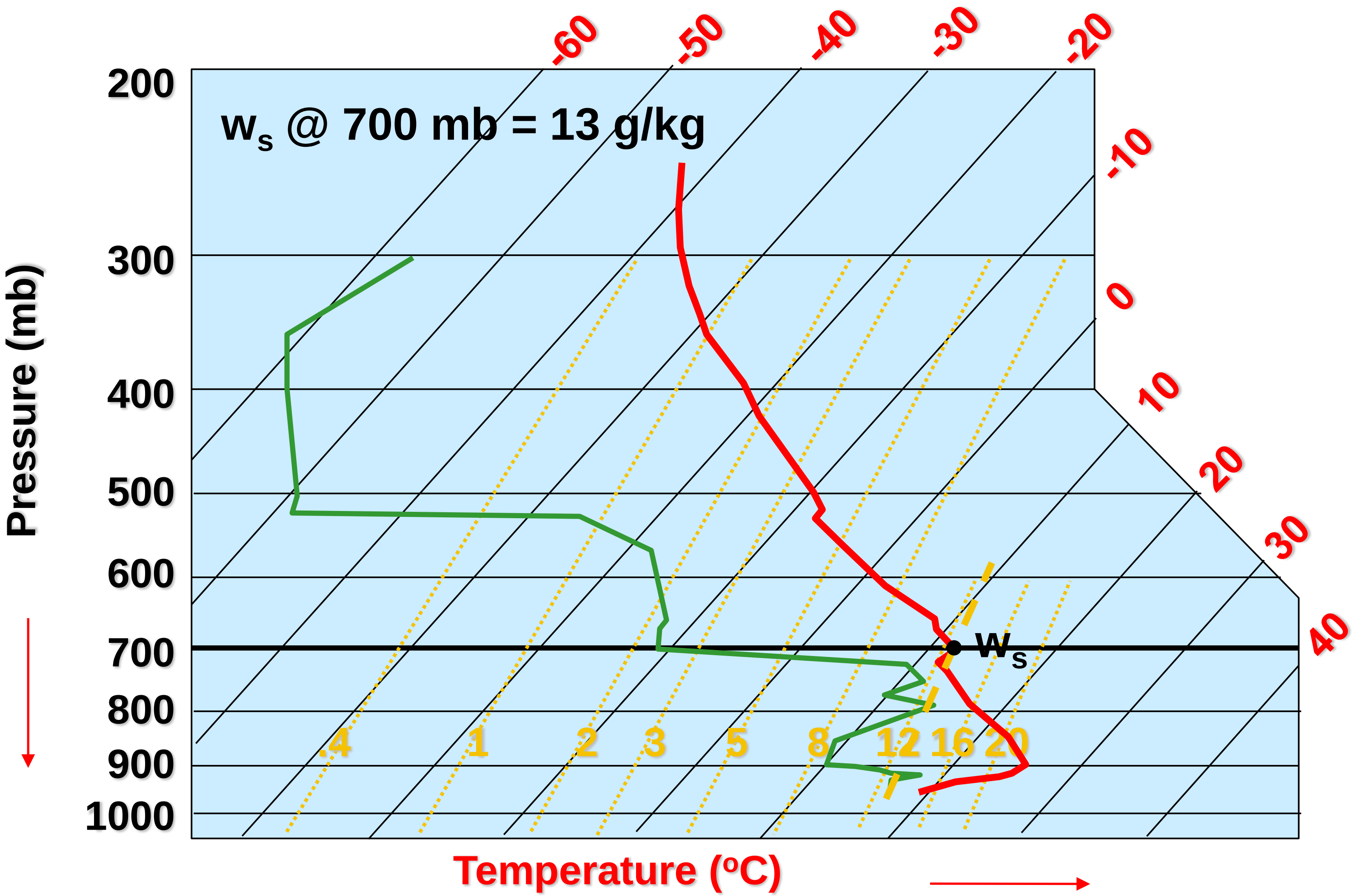
Mixing Ratio (w)



(courtesy F. Remer)

Moist & Thermodynamic Variables

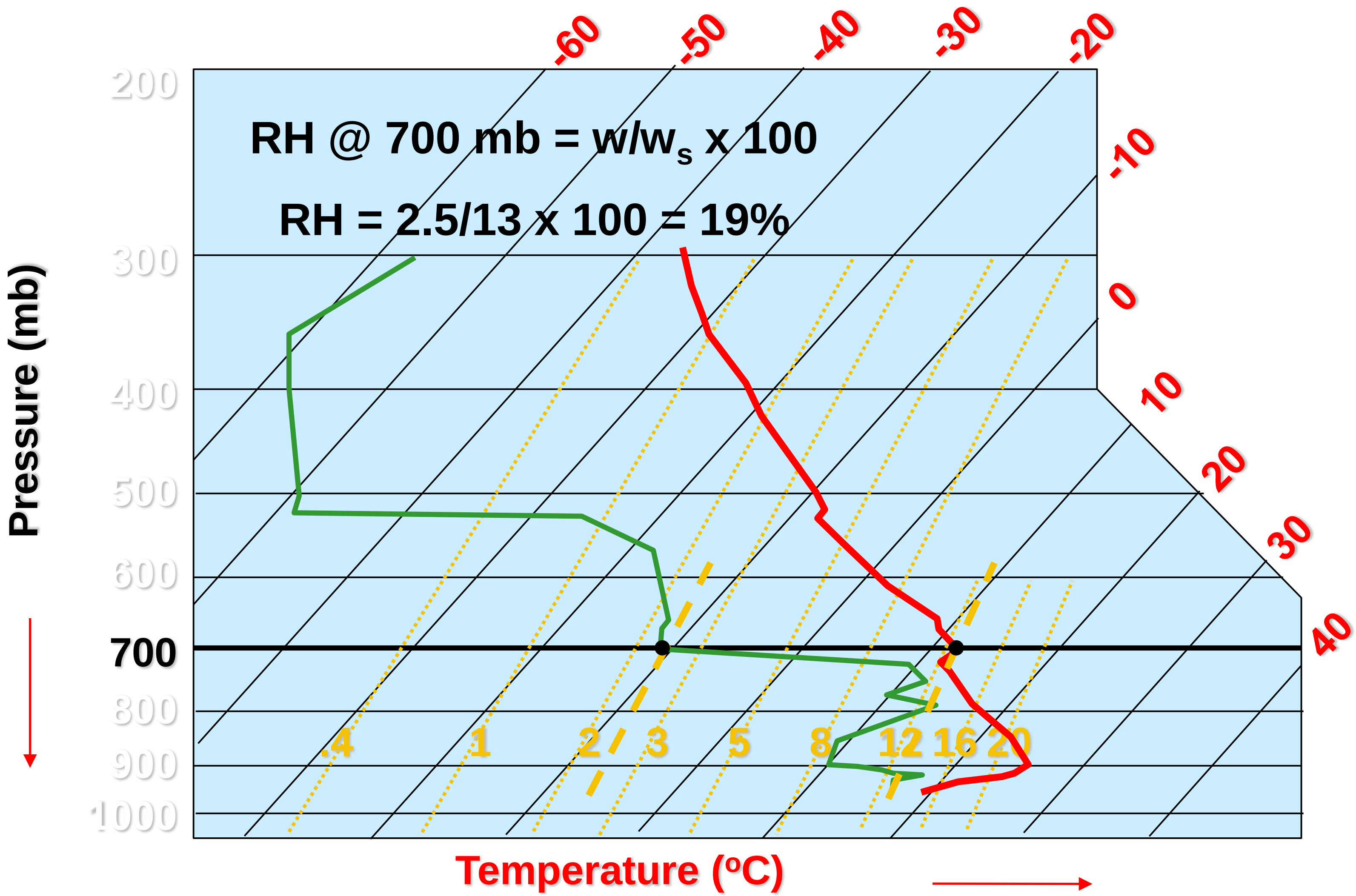
Saturation Mixing Ratio (w_s)



(courtesy F. Remer)

Moist & Thermodynamic Variables

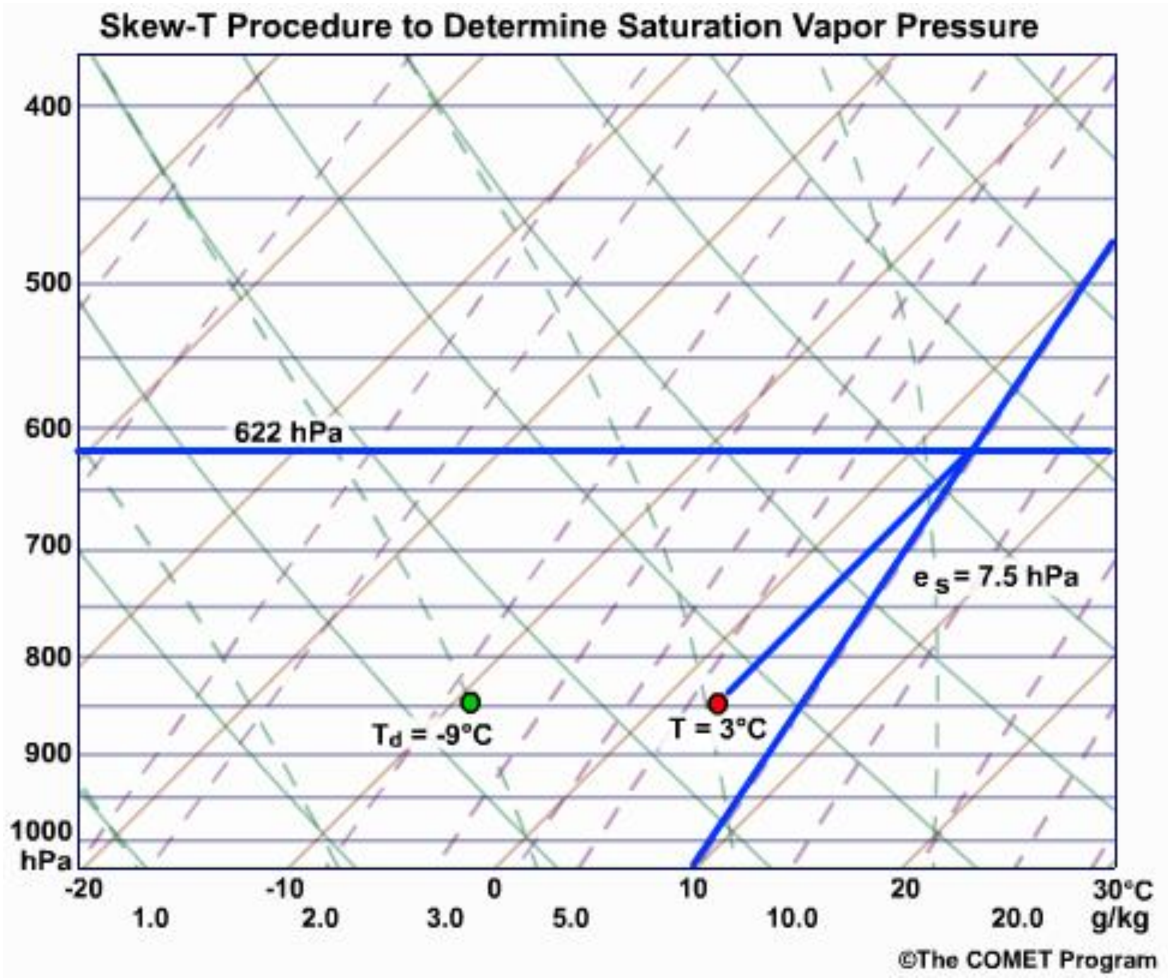
Relative Humidity (RH)



(courtesy F. Remer)

Moist & Thermodynamic Variables

Saturation Vapor Pressure (e_s)



- Step 1: move from T along an isotherm until p=622 hPa
- Step 2: interpolate the value of mixing ratio (or specific humidity)

The value of 622 hPa is not magic. Simply it is chosen because:

$$q = 0.622\ \frac{e}{p}$$

At p=622 hPa:

$$q = 0.622\ \frac{e}{622} = \frac{e}{1000}$$

Thus:

$$q_s = \frac{e_s}{1000}$$

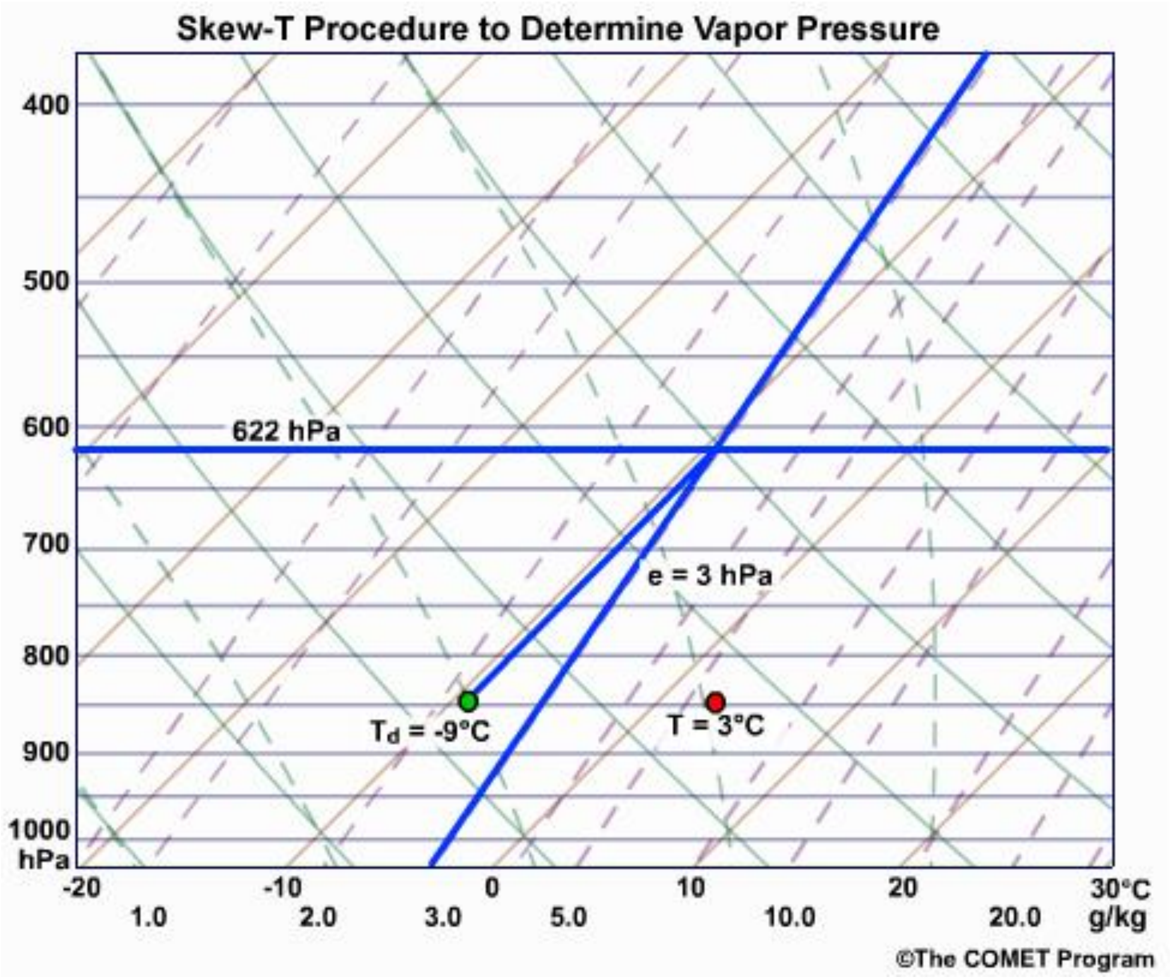
and, having moved on an isotherm:

$$e_{s,622.T} = e_{s,p.T}$$

https://www.meted.ucar.edu/

Moist & Thermodynamic Variables

Vapor Pressure (e)



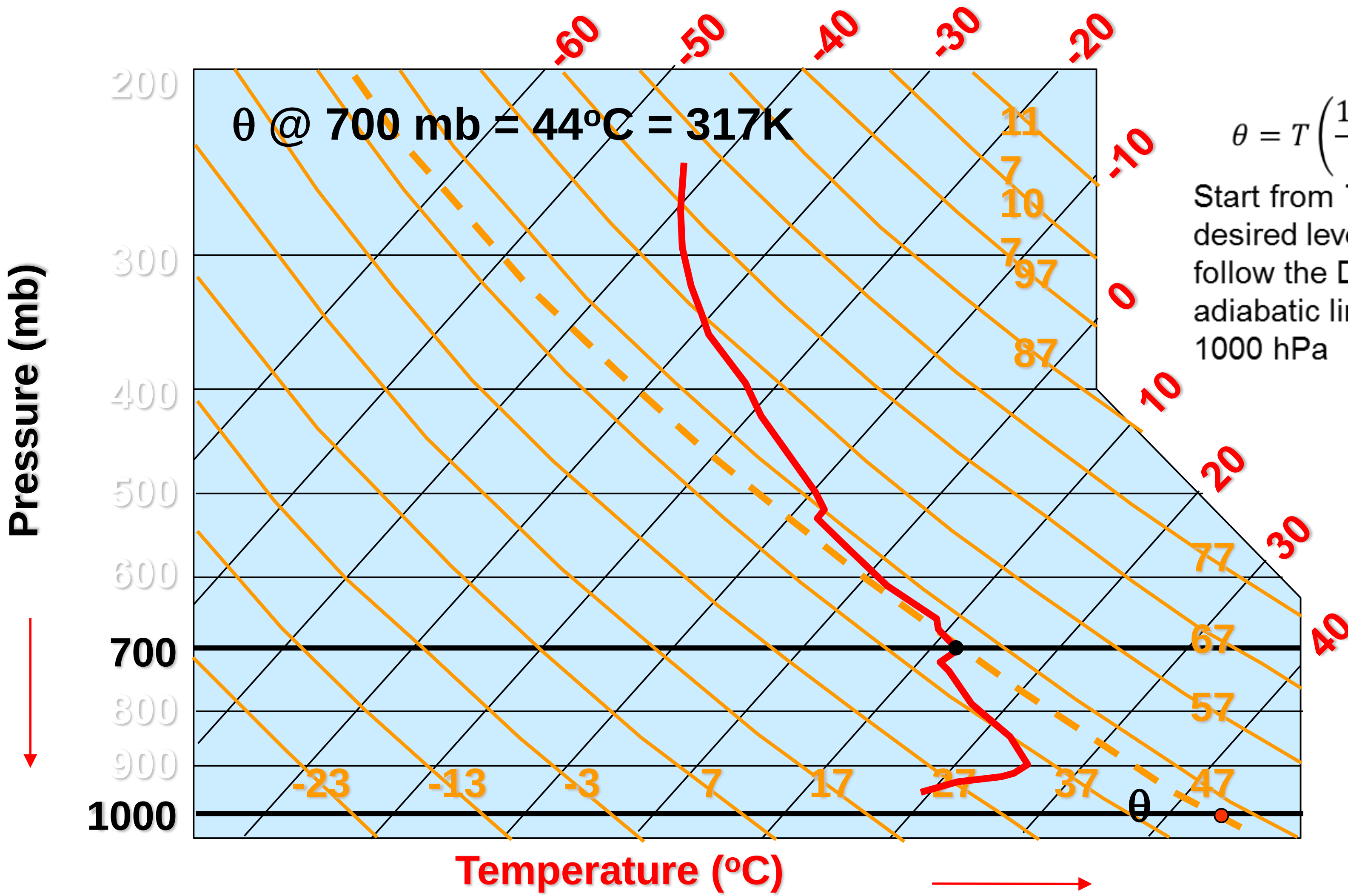
Same as before but starting from T_d:

- Step 1: move from T_d along an isotherm until p=622 hPa
- Step 2: interpolate the value of mixing ratio (or specific humidity)

https://www.meted.ucar.edu/

Moist & Thermodynamic Variables

Potential Temperature (θ)



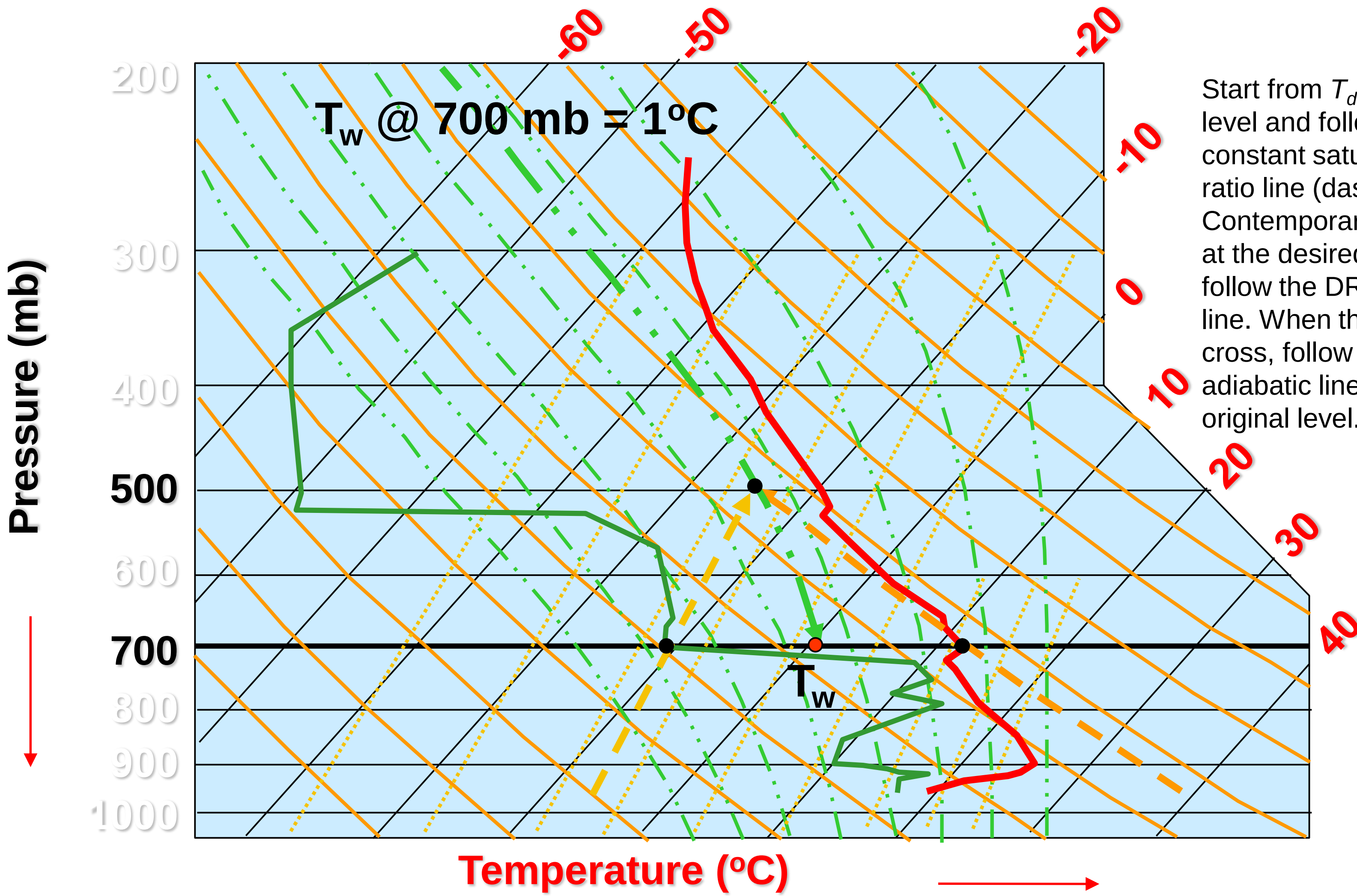
$$\theta = T\left(\frac{1000}{p}\right)^{R_d/c_p}$$

Start from *T* at the desired level, then follow the DRY adiabatic line up to 1000 hPa

(courtesy F. Remer)

Moist & Thermodynamic Variables

Wet Bulb Temperature (T_w)

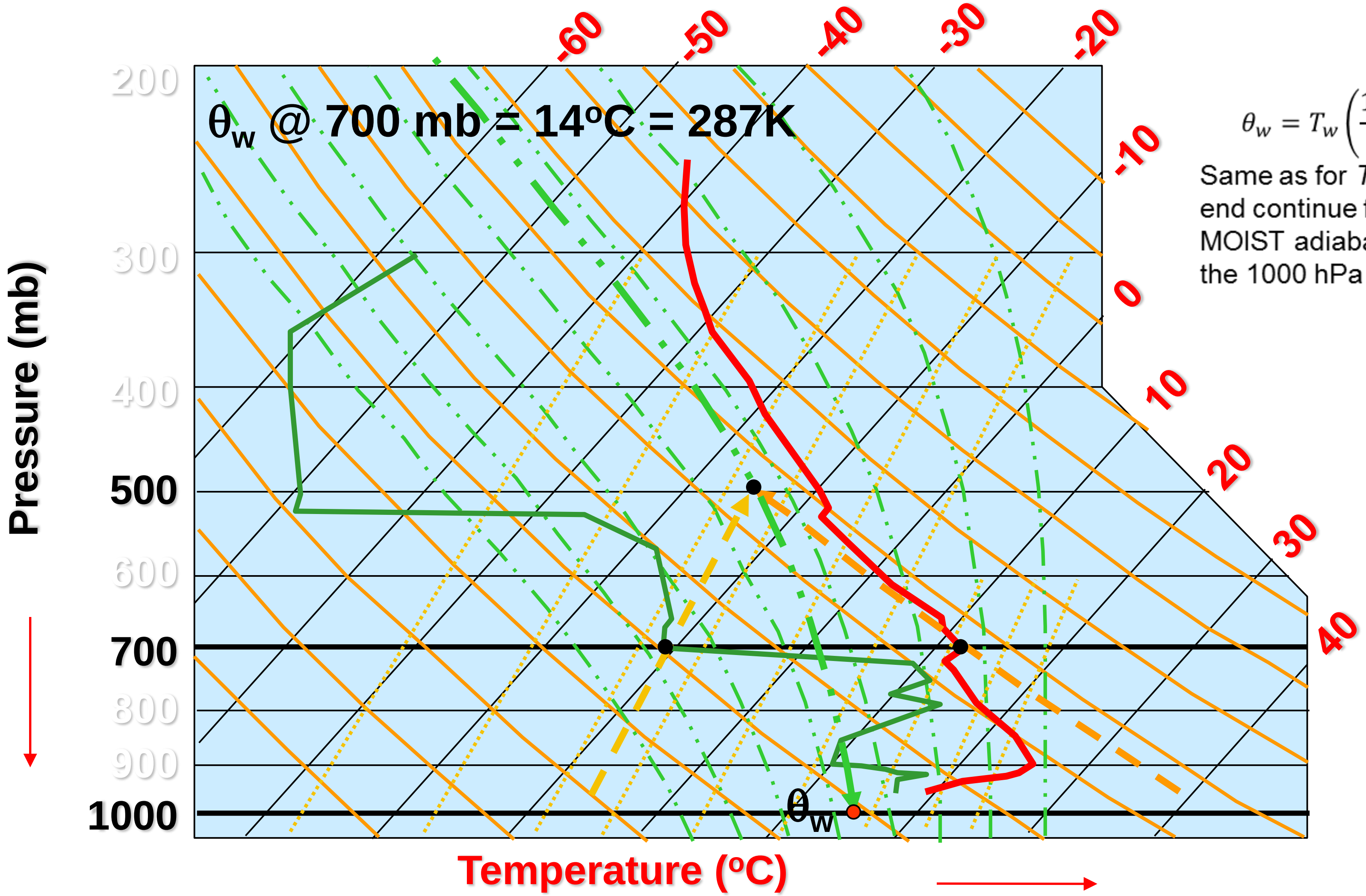


Start from T_d at the desired level and follow the constant saturated mixing ratio line (dashed). Contemporary start from T at the desired level and follow the DRY adiabatic line. When the two lines cross, follow the MOIST adiabatic line up to the original level.

(courtesy F. Remer)

Moist & Thermodynamic Variables

Wet Bulb Potential Temperature (θ_w)



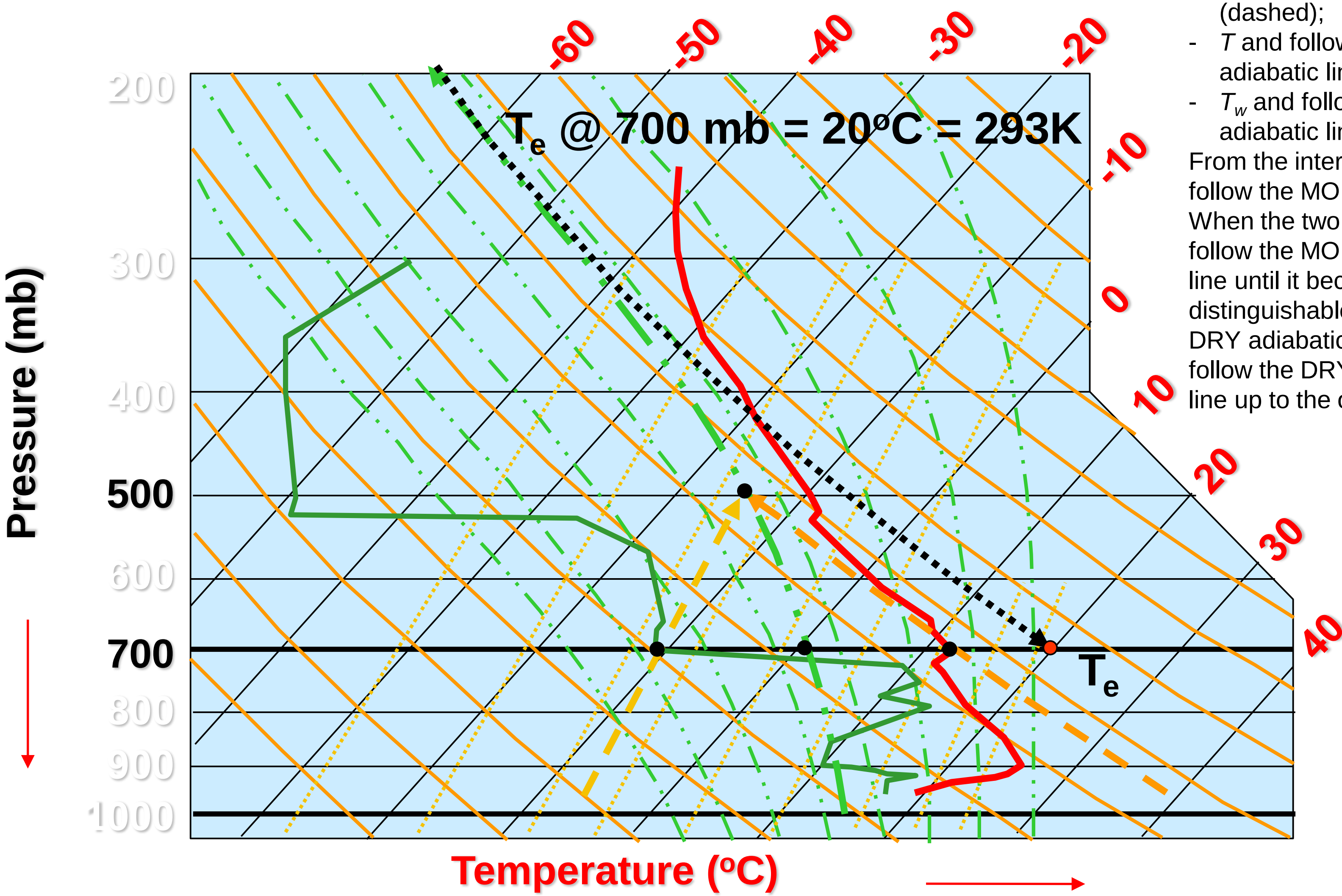
$$\theta_w = T_w \left(\frac{1000}{p}\right)^{R_d/c_p}$$

Same as for T_w, but at the end continue following the MOIST adiabatic line up to the 1000 hPa level.

(courtesy F. Remer)

Moist & Thermodynamic Variables

Equivalent Temperature (T_e)



Start from two of these three at the desired level:

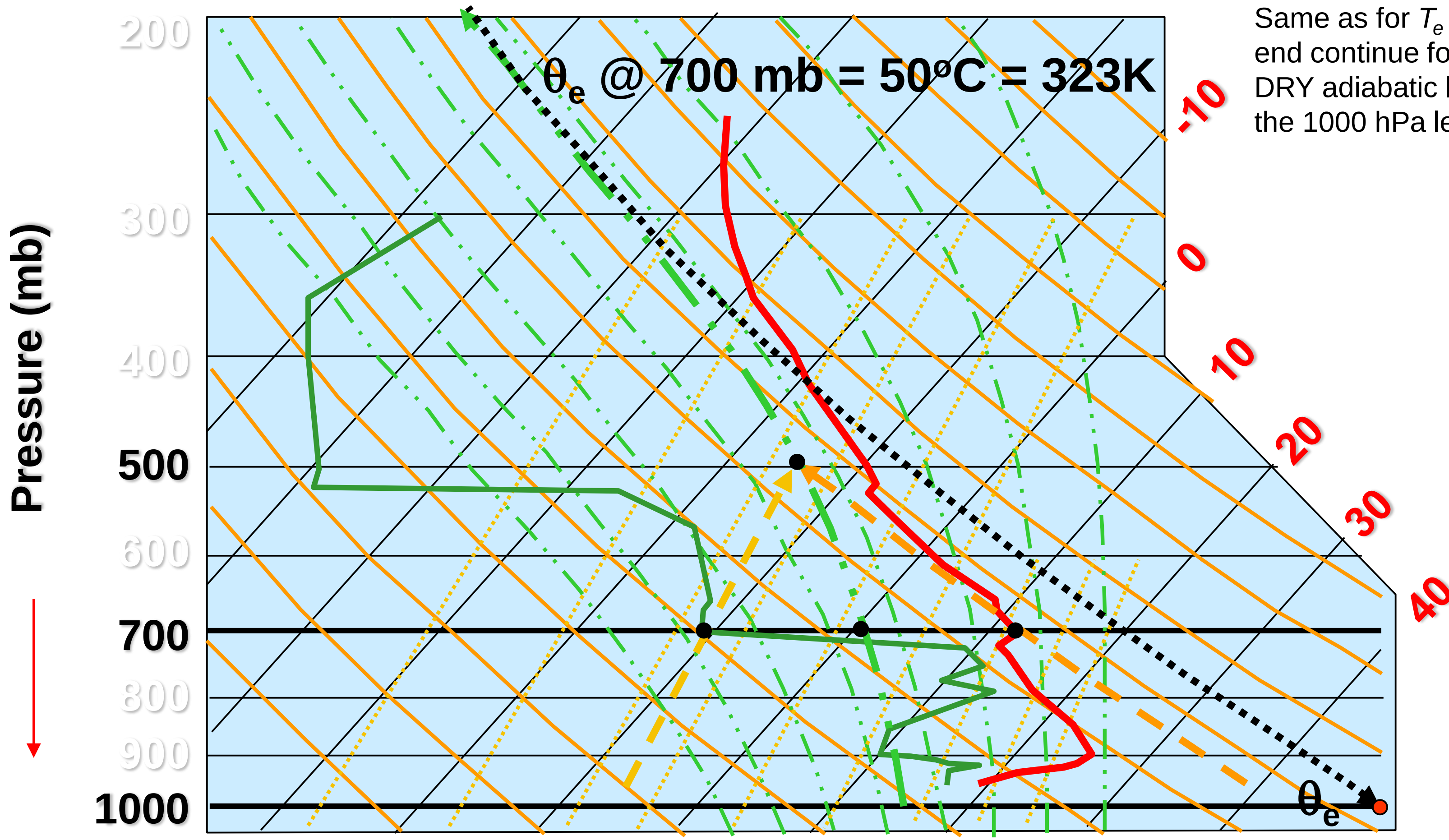
- T_d and follow the constant saturated mixing ratio line (dashed);
- *T* and follow the DRY adiabatic line;
- T_w and follow the MOIST adiabatic line.

From the intersection point, follow the MOIST .
When the two lines cross, follow the MOIST adiabatic line until it become not distinguishable from the DRY adiabatic line, then follow the DRY adiabatic line up to the original level.

(courtesy F. Remer)

Moist & Thermodynamic Variables

Equivalent Potential Temperature (θ_e)



Same as for T_e , but at the end continue following the DRY adiabatic line up to the 1000 hPa level.

(courtesy F. Remer)

Moist & Thermodynamic Variables

T_e & θ_e

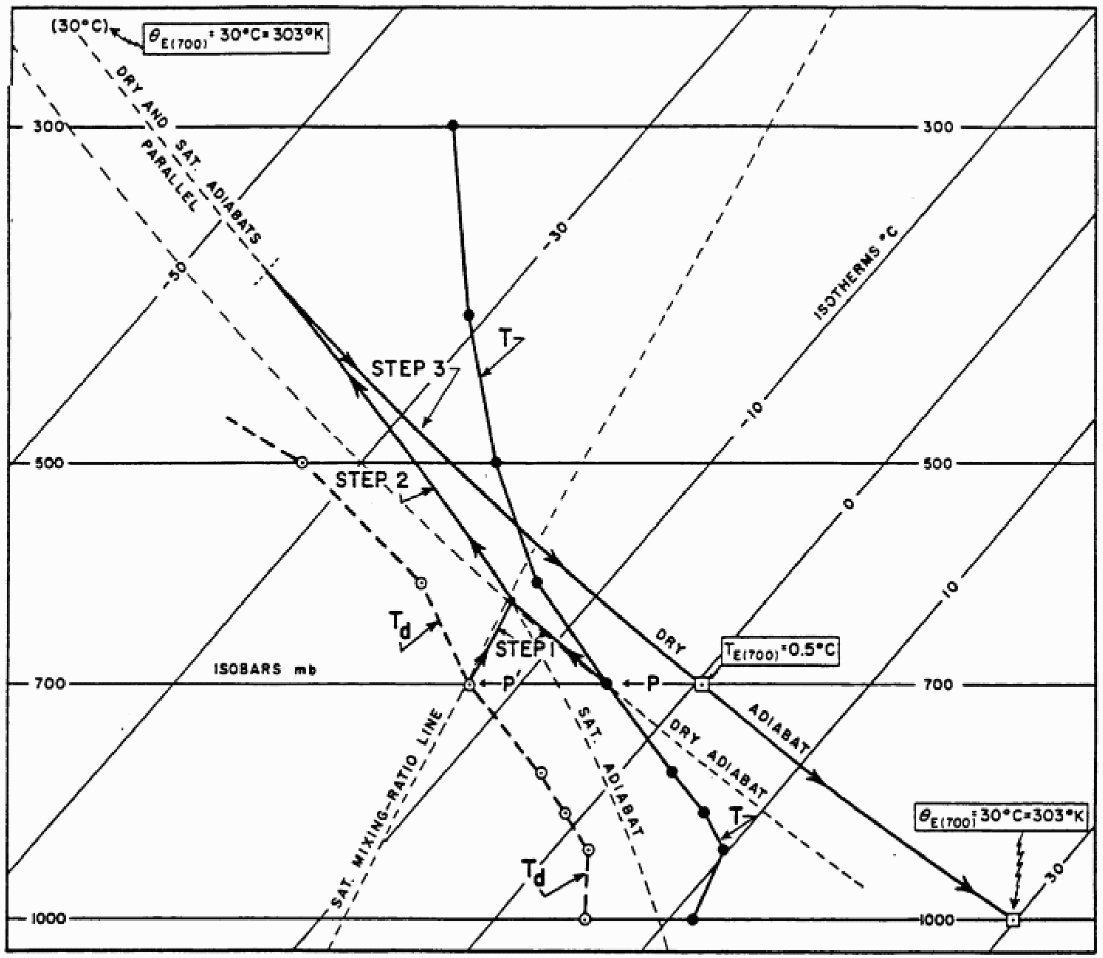
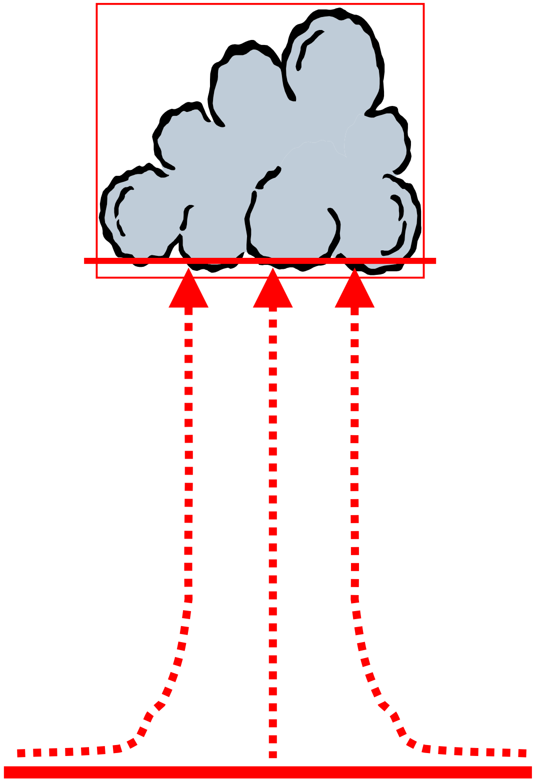


Figure 3. Determination of the Equivalent Temperature (T_E) and the Equivalent Potential Temperature (θ_E). (from AWS/TR-79/006, 1979)

Auto-Convective Ascent

Convective Condensation Level (CCL)

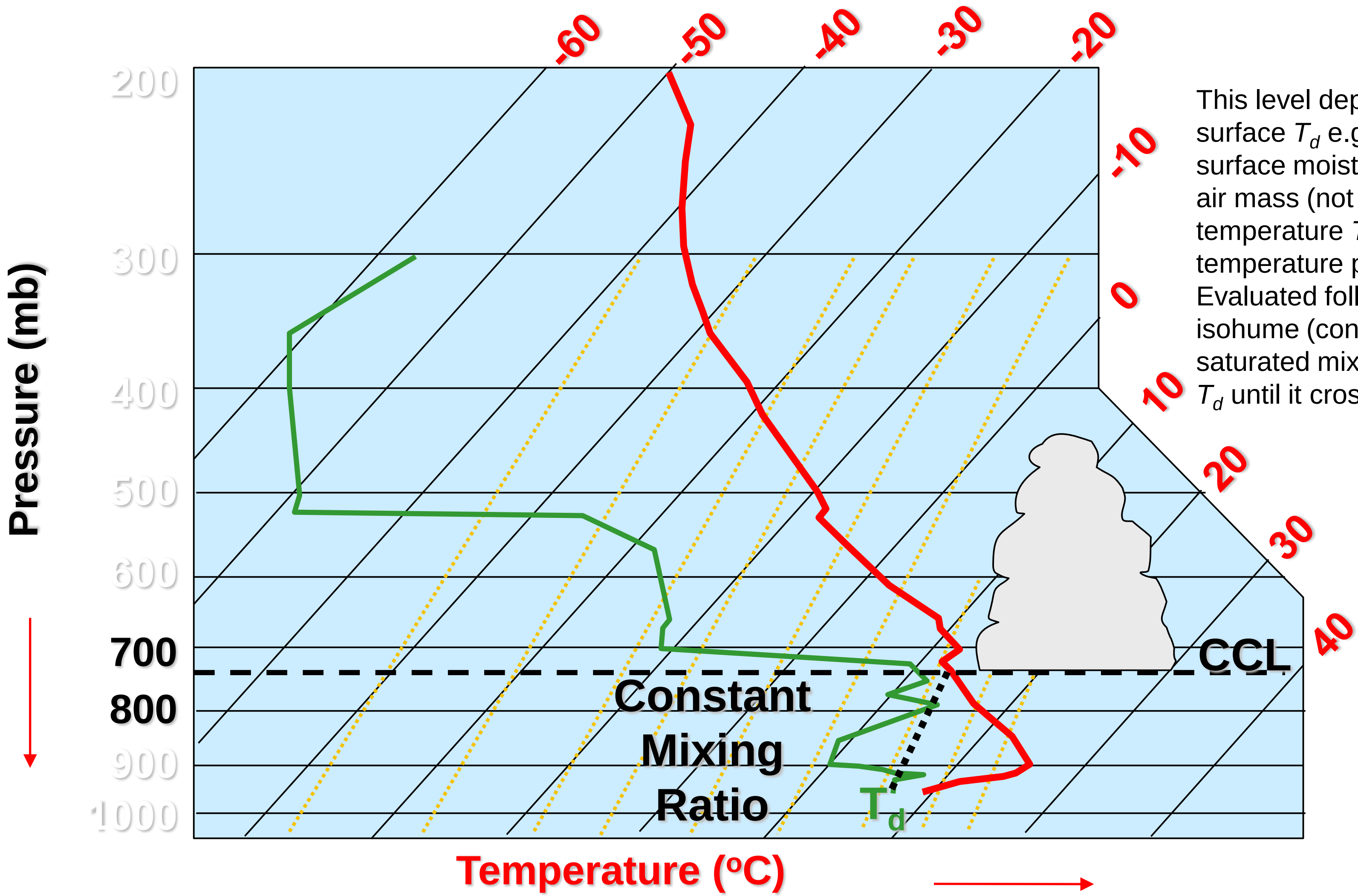
- The height to which a parcel of air, if heated sufficiently from below, will rise adiabatically until it is just saturated.
- The height of the base of cumuliform clouds which are produced by thermal convection from surface heating



(courtesy F. Remer)

Auto-Convective Ascent

Convective Condensation Level (CCL)

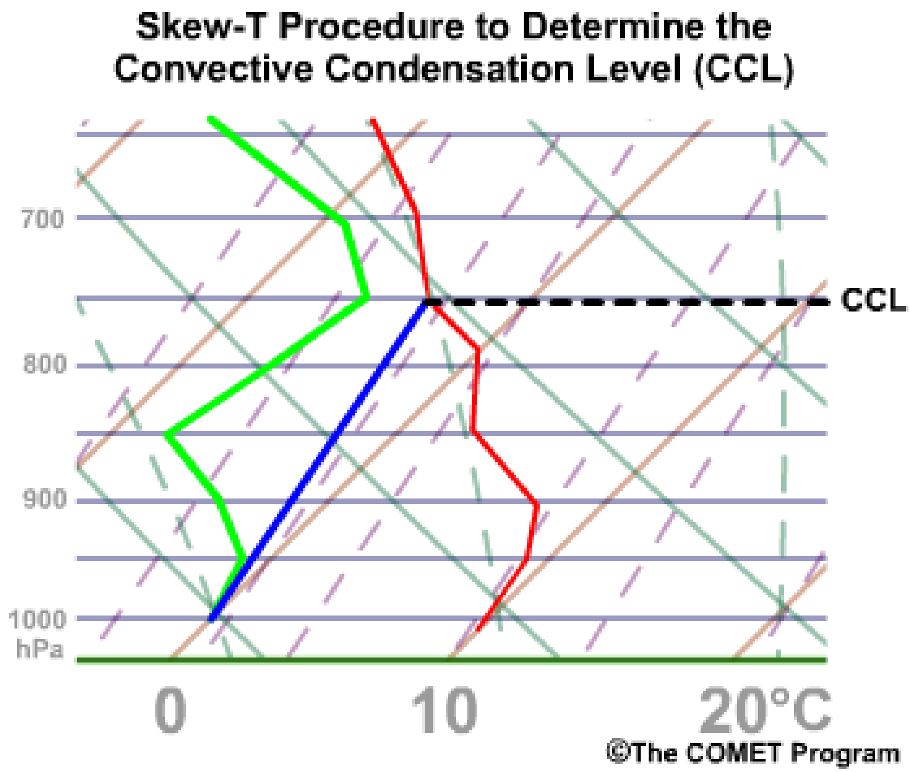


This level depends only on surface T_d e.g. on the surface moisture content of air mass (not on its surface temperature *T*) and on temperature profile *T(z)* Evaluated following the isohume (constant saturated mixing ratio) from T_d until it crosses *T(z)*

(courtesy F. Remer)

Auto-Convective Ascent

Convective Condensation Level (CCL)

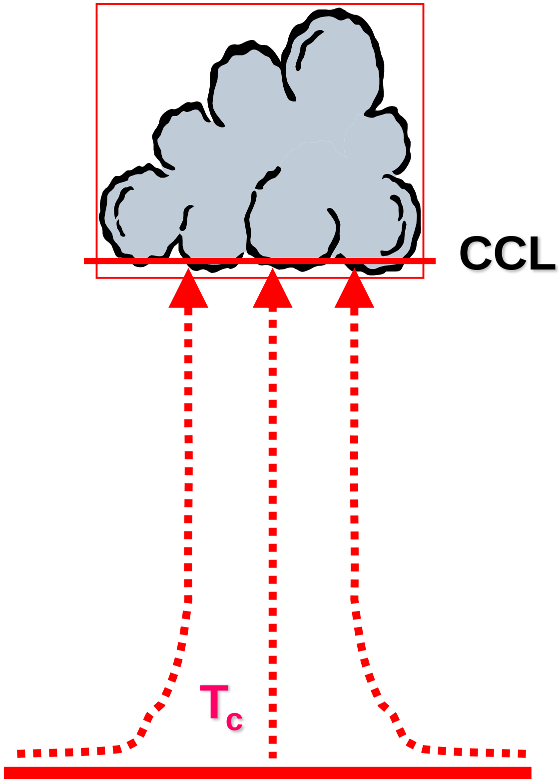


https://www.meted.ucar.edu/

Auto-Convective Ascent

Convective Temperature (T_c)

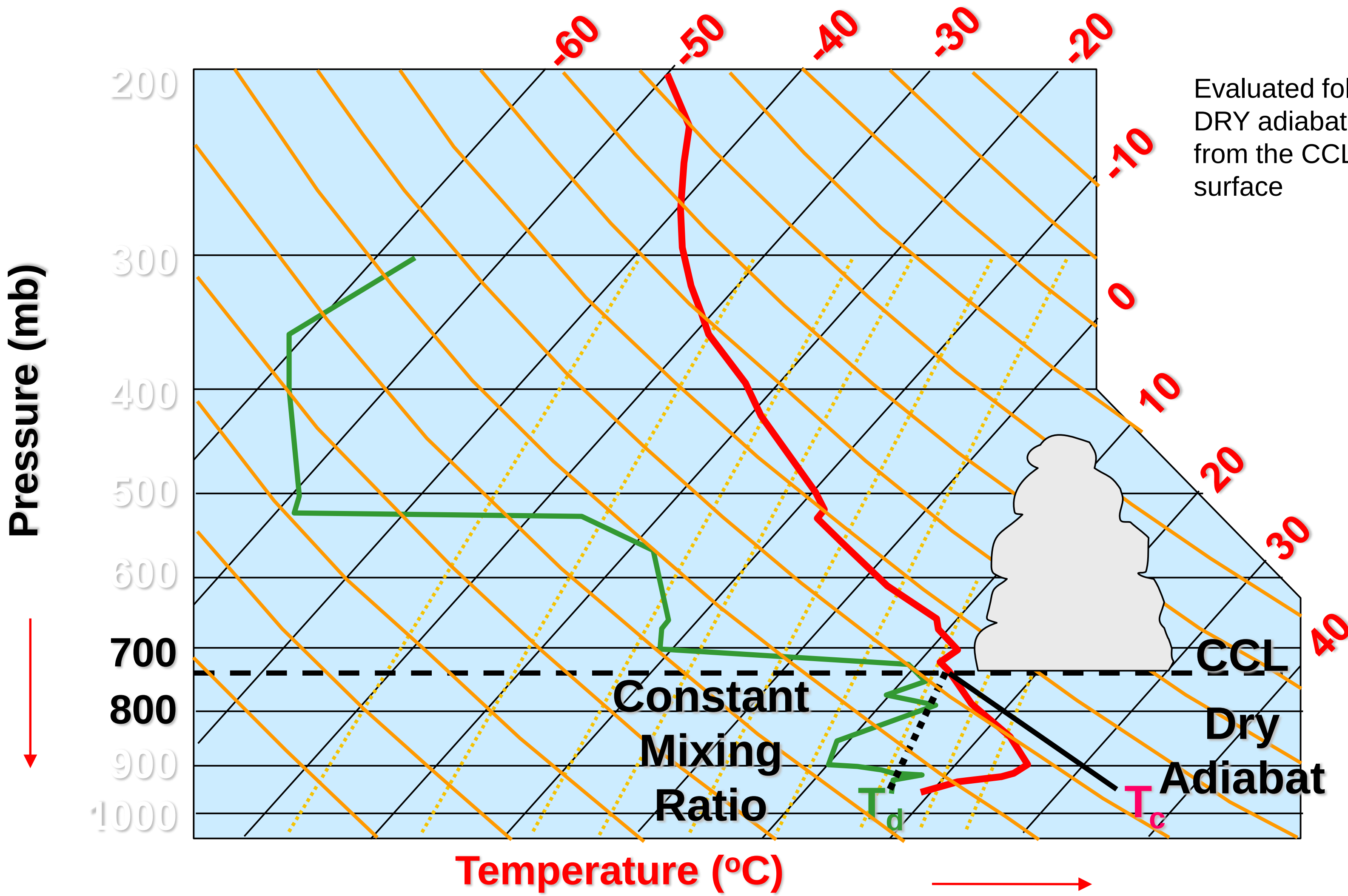
- The surface temperature that must be reached to start the formation of convective clouds by solar heating



(courtesy F. Remer)

Auto-Convective Ascent

Convective Temperature (T_c)

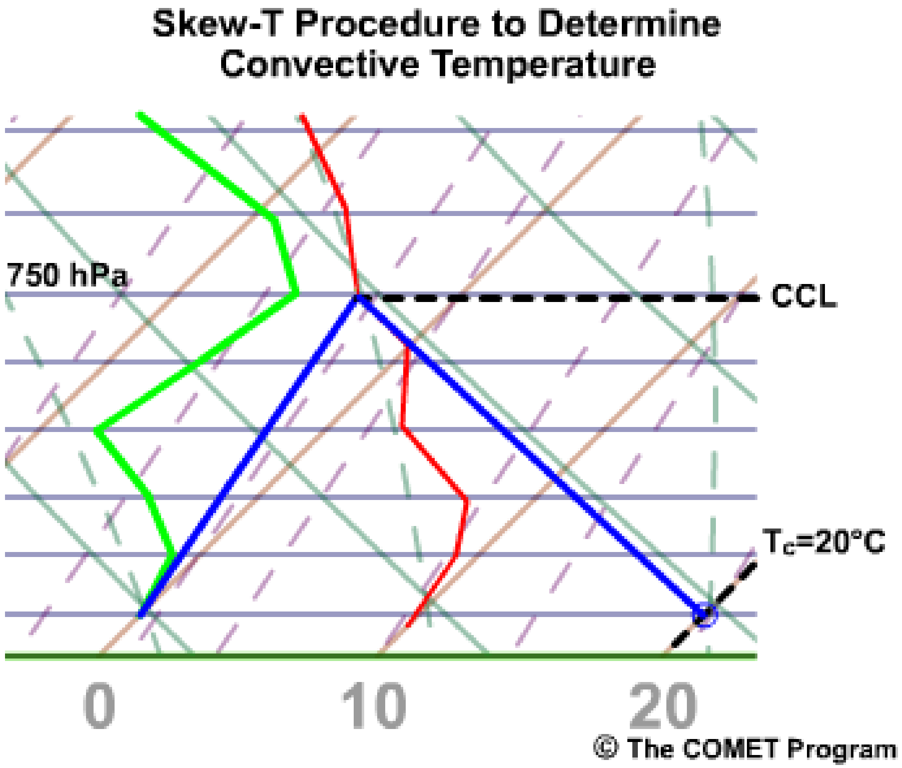


Evaluated following the DRY adiabatic line down from the CCL up to the surface

(courtesy F. Remer)

Auto-Convective Ascent

Convective Temperature (T_c)



https://www.meted.ucar.edu/

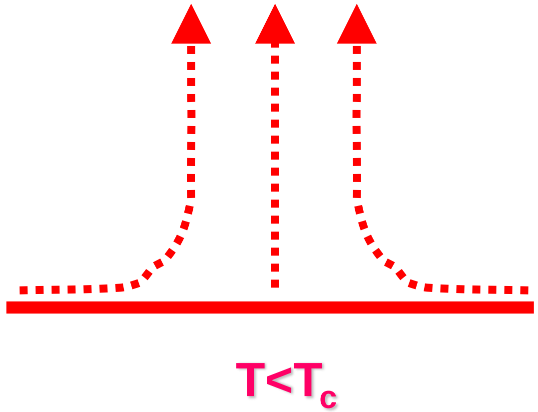
Auto-Convective Ascent

Forecasting Convective Clouds

- Would the afternoon temperature (T) be higher than T_c?

NO!

- Thermals may form, but will not rise high enough to condense.



(courtesy F. Remer)

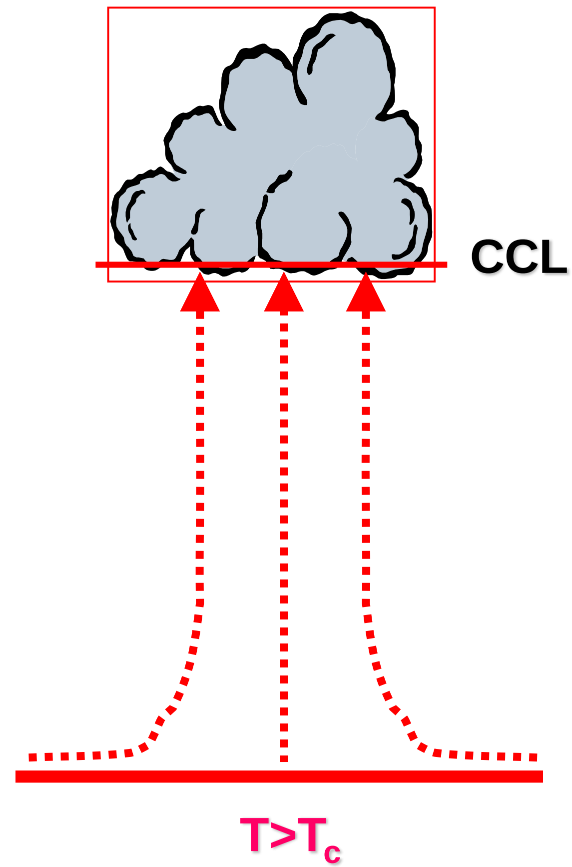
Auto-Convective Ascent

Forecasting Convective Clouds

- Would the afternoon temperature (T) be higher than T_c?

YES!

- Thermals will rise high enough to condense.

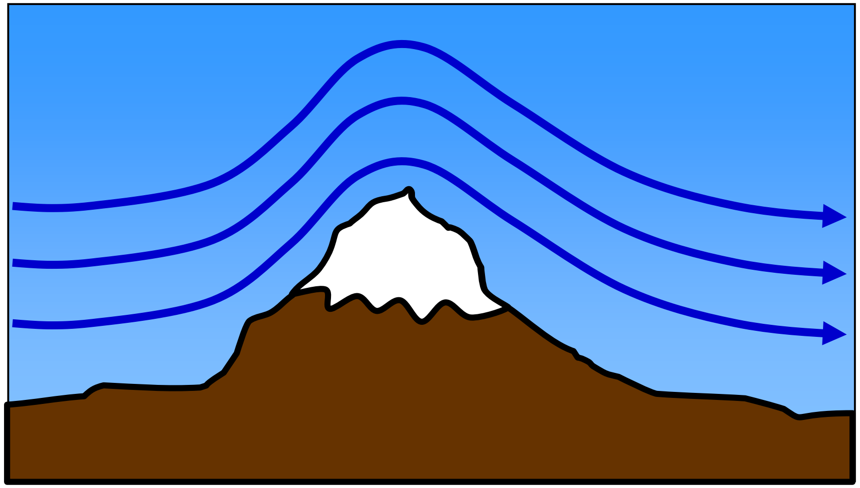


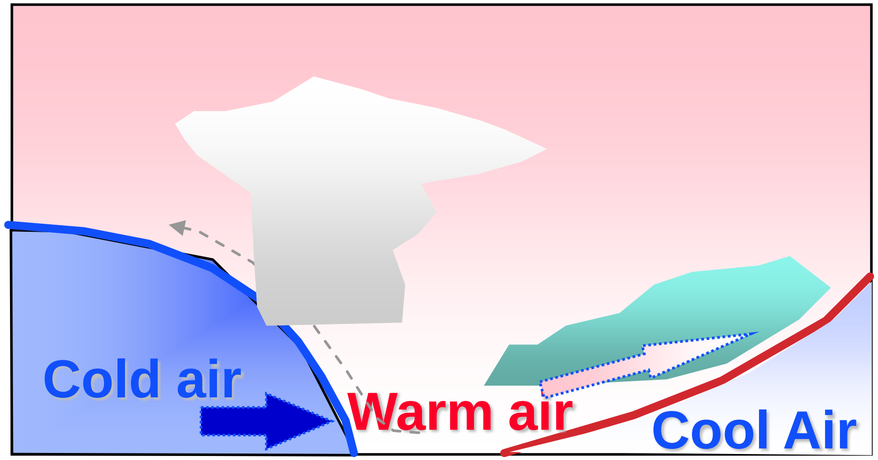
(courtesy F. Remer)

Forced Lifting

Forcing Mechanisms to Lift Air Parcel

- Mostly by synoptic scale features



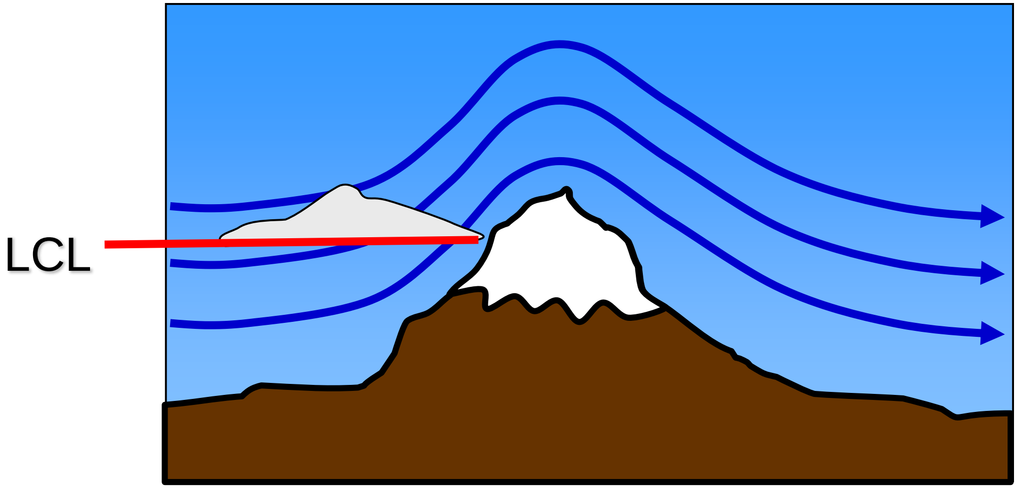


(courtesy F. Remer)

Forced Lifting

Lifting Condensation Level (LCL)

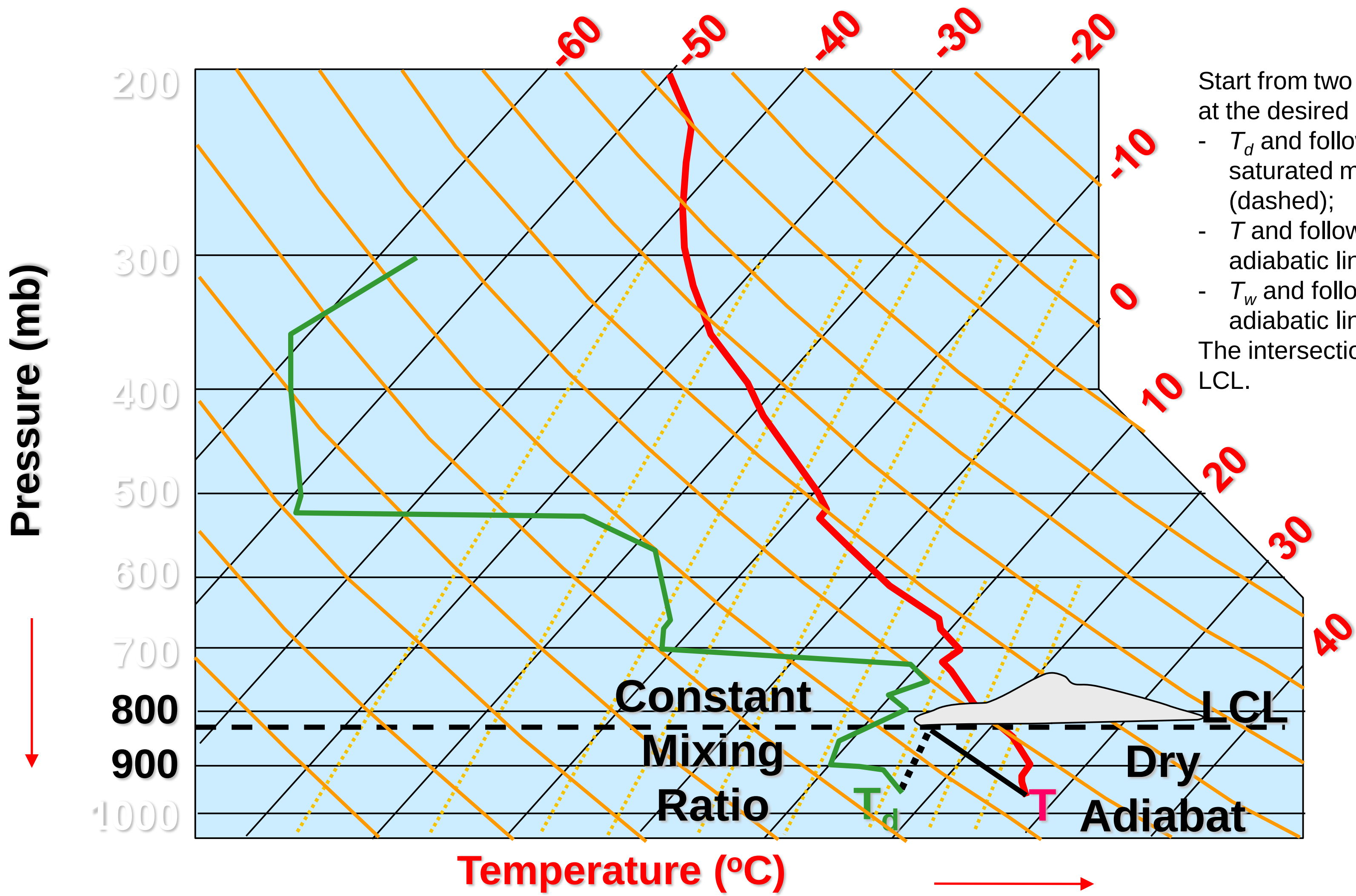
- The height at which a parcel of air becomes saturated when it is lifted dry adiabatically.
- The LCL differs from the CCL as here the temperature of lifting air mass decreases dry-adiabatically



(courtesy F. Remer)

Forced Lifting

Lifting Condensation Level (LCL)



Start from two of these three at the desired level:

- T_d and follow the constant saturated mixing ratio line (dashed);
- T and follow the DRY adiabatic line;
- T_w and follow the MOIST adiabatic line.

The intersection point is the LCL.

(courtesy F. Remer)

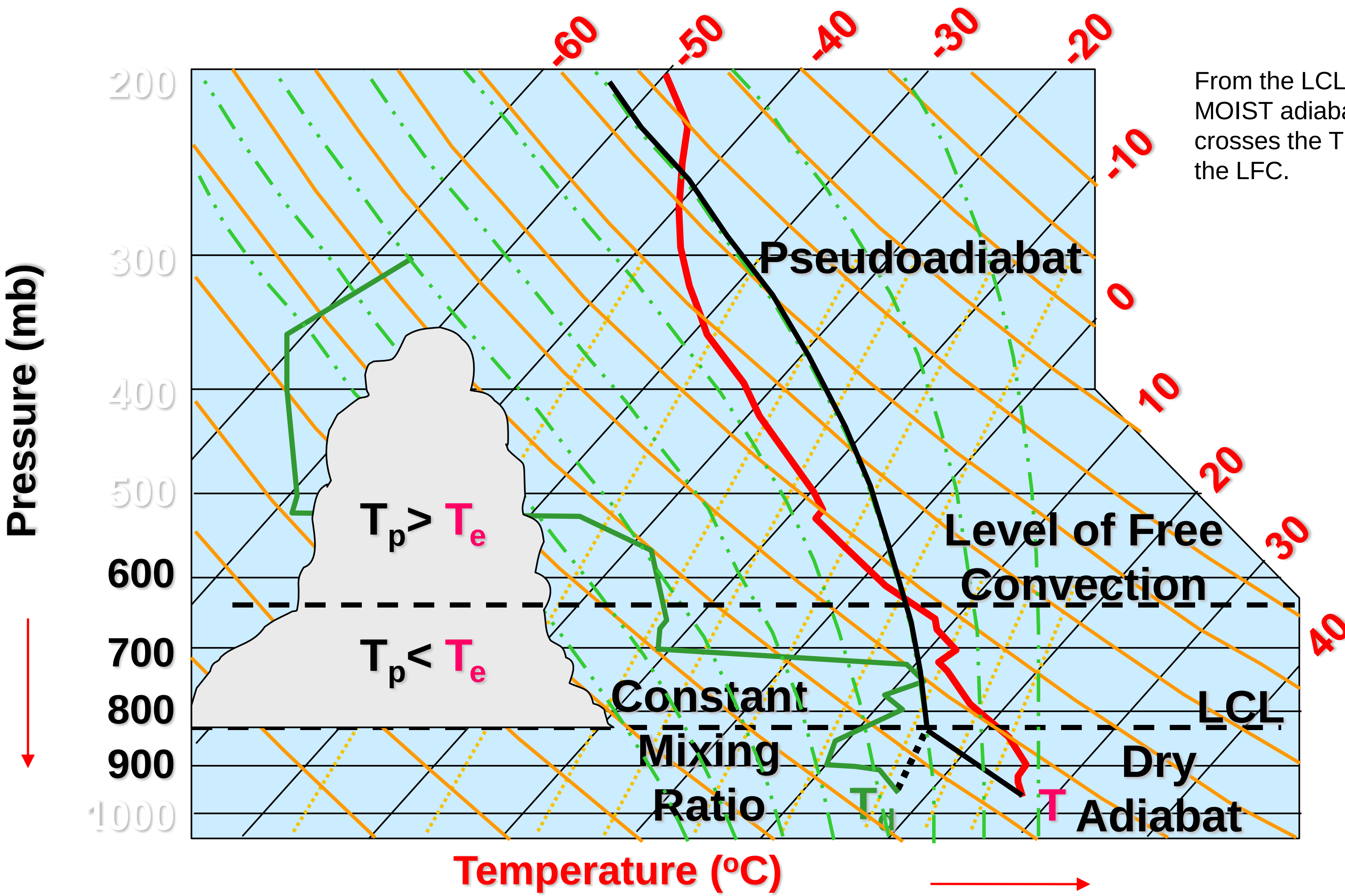
Forced Lifting

Level of Free Convection (LFC)

- The height at which a parcel of air lifted dry adiabatically until saturated and pseudoadiabatically thereafter would first become warmer (less dense) than the surrounding air

Forced Lifting

Level of Free Convection (LFC)



From the LCL, follow the MOIST adiabatic line until it crosses the T(z) line: this is the LFC.

(courtesy F. Remer)

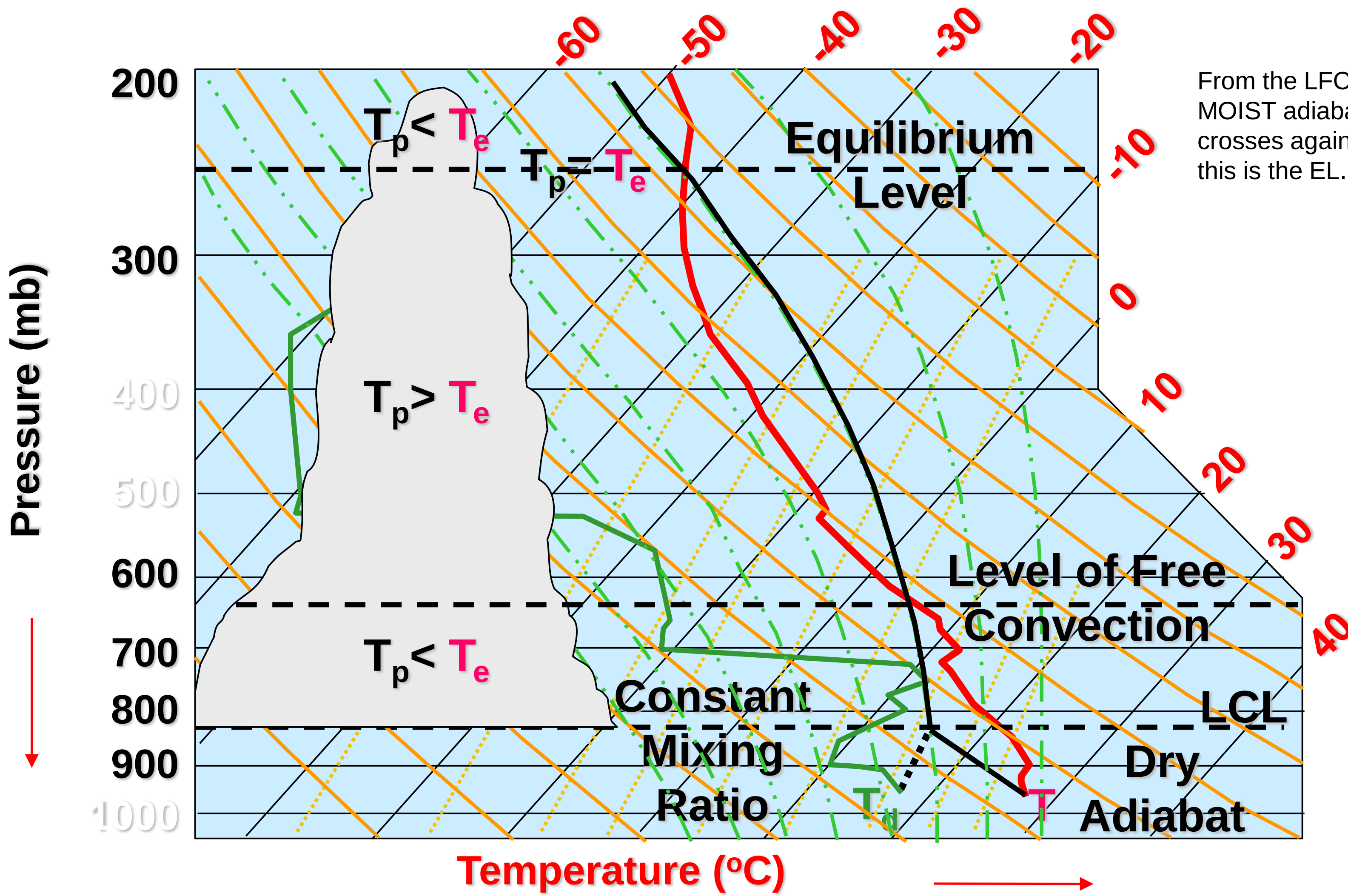
Forced Lifting

Equilibrium Level (EL)

- The height where the temperature of a buoyantly rising parcel again becomes equal to the temperature of the environment
- It is also called Level of Neutral Buoyancy (LNB)

Forced Lifting

Equilibrium Level (EL)

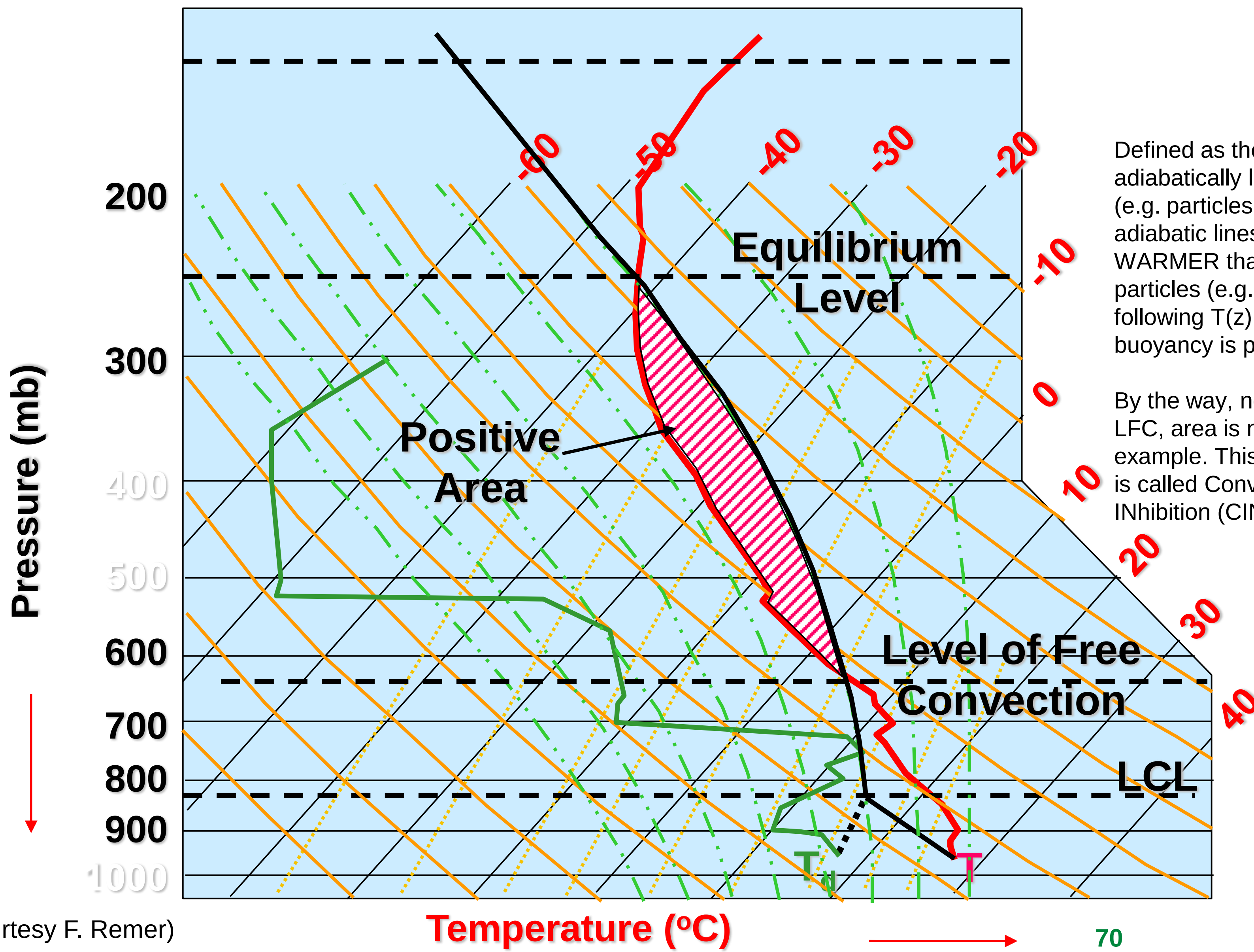


From the LFC, follow the MOIST adiabatic line until it crosses again the T(z) line: this is the EL.

(courtesy F. Remer)

Forced Lifting

Positive & Negative Areas



Defined as the area in which adiabatically lifted particles (e.g. particles following adiabatic lines) are WARMER than local particles (e.g. particles following T(z) line). Here, buoyancy is positive.

By the way, note that, below LFC, area is negative, in this example. This negative area is called Convective INhibition (CIN).

(courtesy F. Remer)

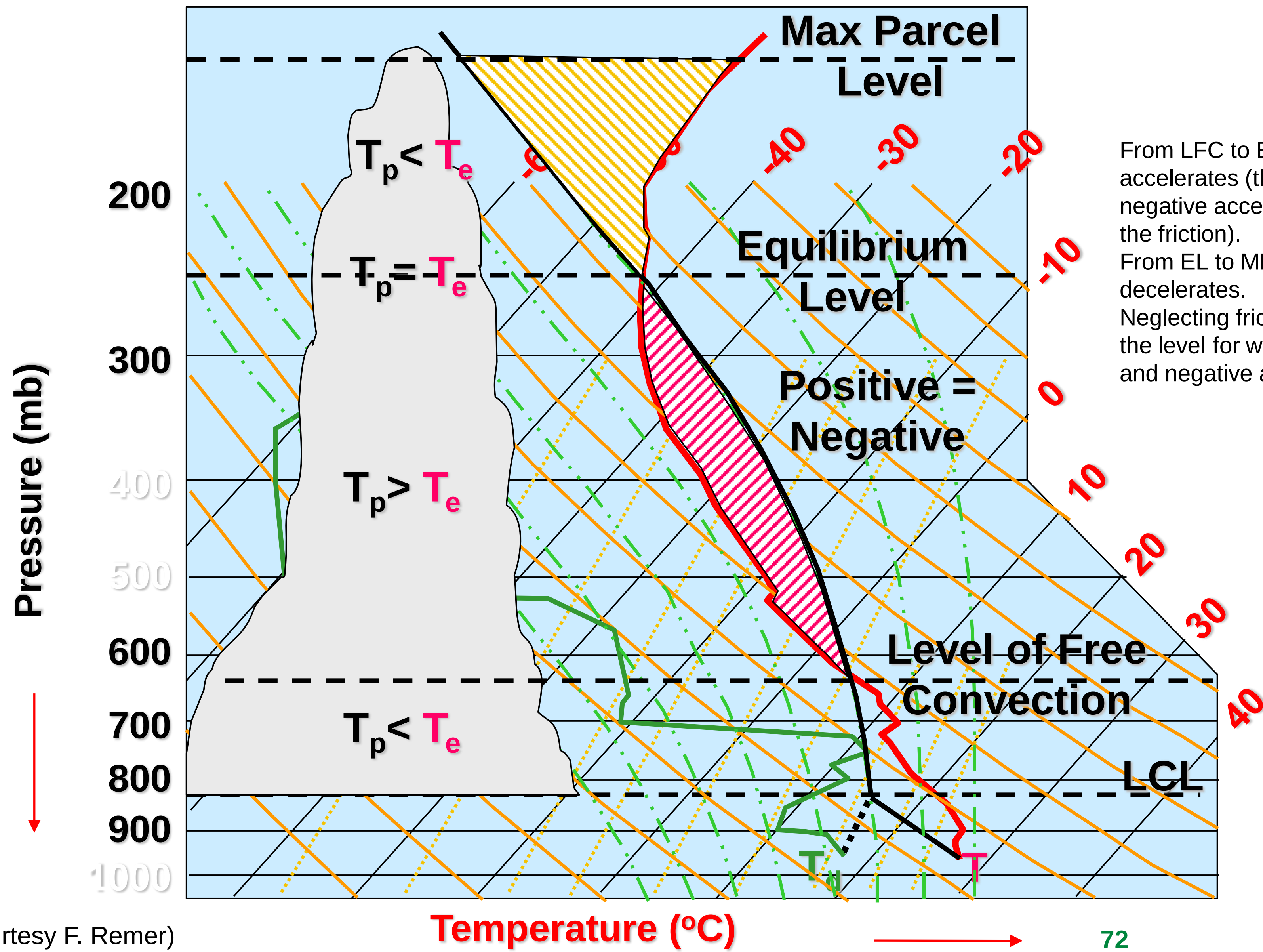
Forced Lifting

Maximum Parcel Level (MPL)

- The maximum height a thunderstorm will build in the atmosphere using pure bouyancy theory. The MPL is higher than the EL (Equilibrium Level) since updraft momentum carries the updraft higher as the updraft decelerates.
- Above the EL, the parcel becomes colder than the environment (negative buoyancy) and decelerates until the point at which it stops at the MPL.

Forced Lifting

Maximum Parcel Level (MPL)



From LFC to EL, a particle accelerates (the only negative acceleration being the friction).
From EL to MPL, the particle decelerates.
Neglecting friction, MPL is the level for which positive and negative areas equal.

(courtesy F. Remer)

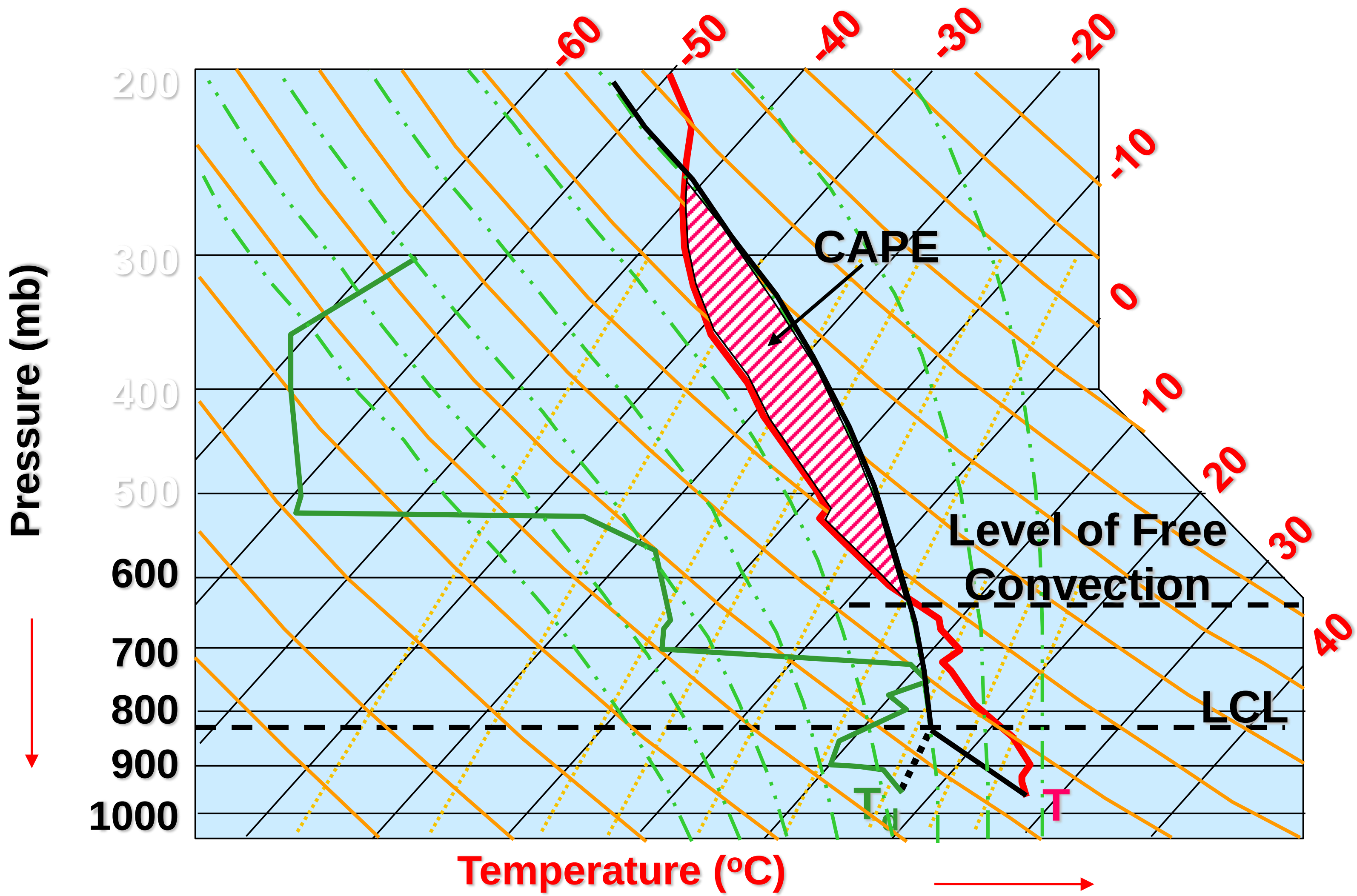
Forced Lifting

Convective Available Potential Energy (CAPE)

- Buoyant energy.
- The area (above the LFC) between the environmental sounding and the pseudoadiabat.
- The integration of the positive area on a Skew T–log P sounding.
- Unlikely Development of Strong Convection
    - CAPE <1000 J kg^{-1}
- Strong or Severe Thunderstorms
    - CAPE ~ 2000 J kg^{-1}

Forced Lifting

Convective Available Potential Energy (CAPE)



(courtesy F. Remer)

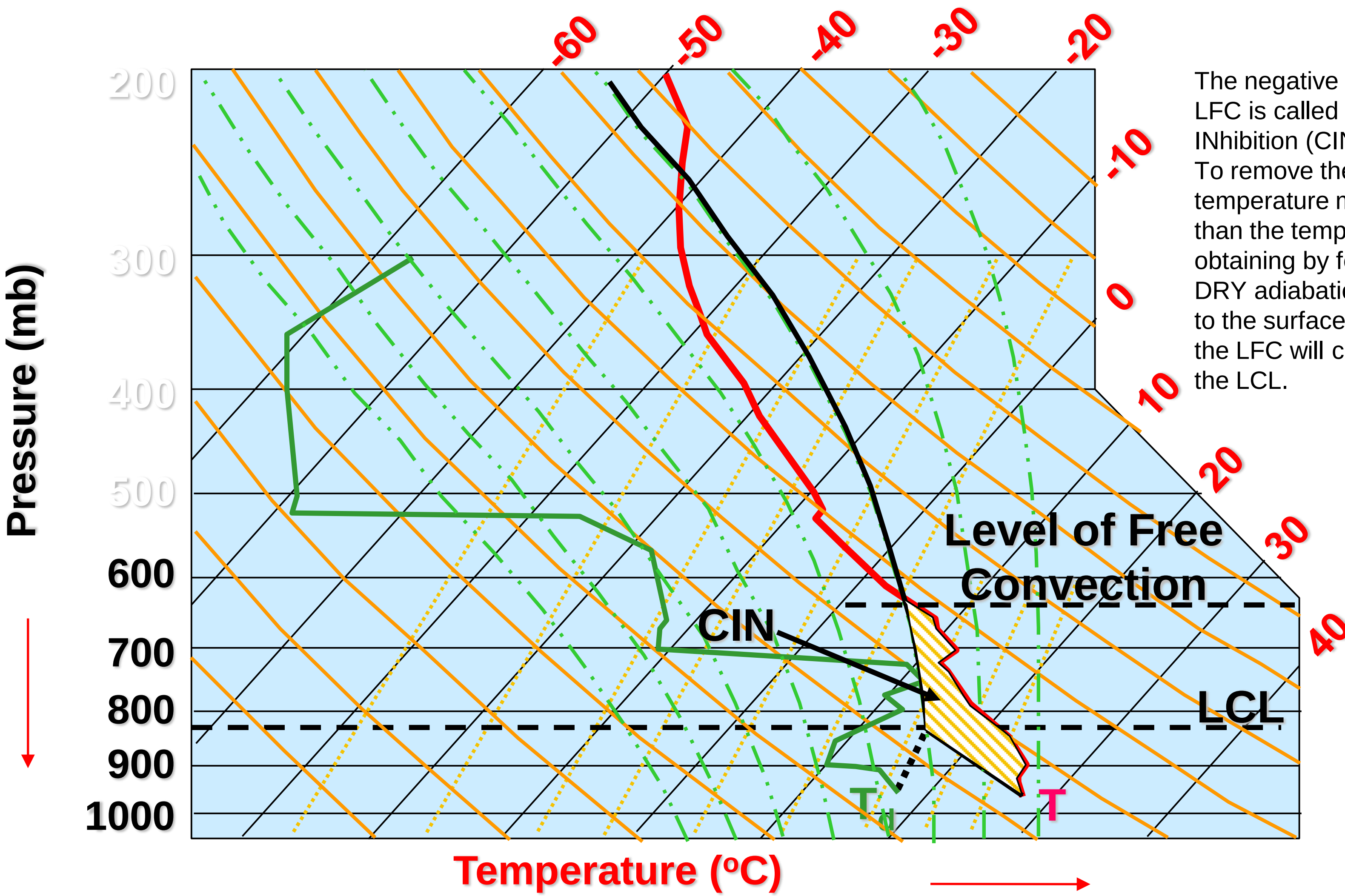
Forced Lifting

Convective Inhibition (CIN)

- Energy required to make a parcel buoyant
- The area (below the LFC) between the environmental sounding and the:
  - Dry adiabat if unsaturated
  - Pseudo adiabat if saturated
- This is the region where a parcel of air if raised from the lower PBL would sink back down again (i.e., stable layer).
- Another term for CIN is a capping layer. The capping layer must be broken before lower PBL based lifting is able to move into the CAPE region of a sounding and develop into deep convection.
- Early Development of Convection
  - 10 m^2s^2
- Squall Lines
  - 50 m^2s^2
- No Thunderstorms (‘Capped’)
  - 150 m^2s^2

Forced Lifting

Convective Inhibition (CIN)



The negative area below the LFC is called Convective INhibition (CIN).
To remove the CIN, temperature must be larger than the temperature obtaining by following the DRY adiabatic line from T_{LFC} to the surface. In this case, the LFC will coincide with the LCL.

(courtesy F. Remer)

Forced Lifting

Summary

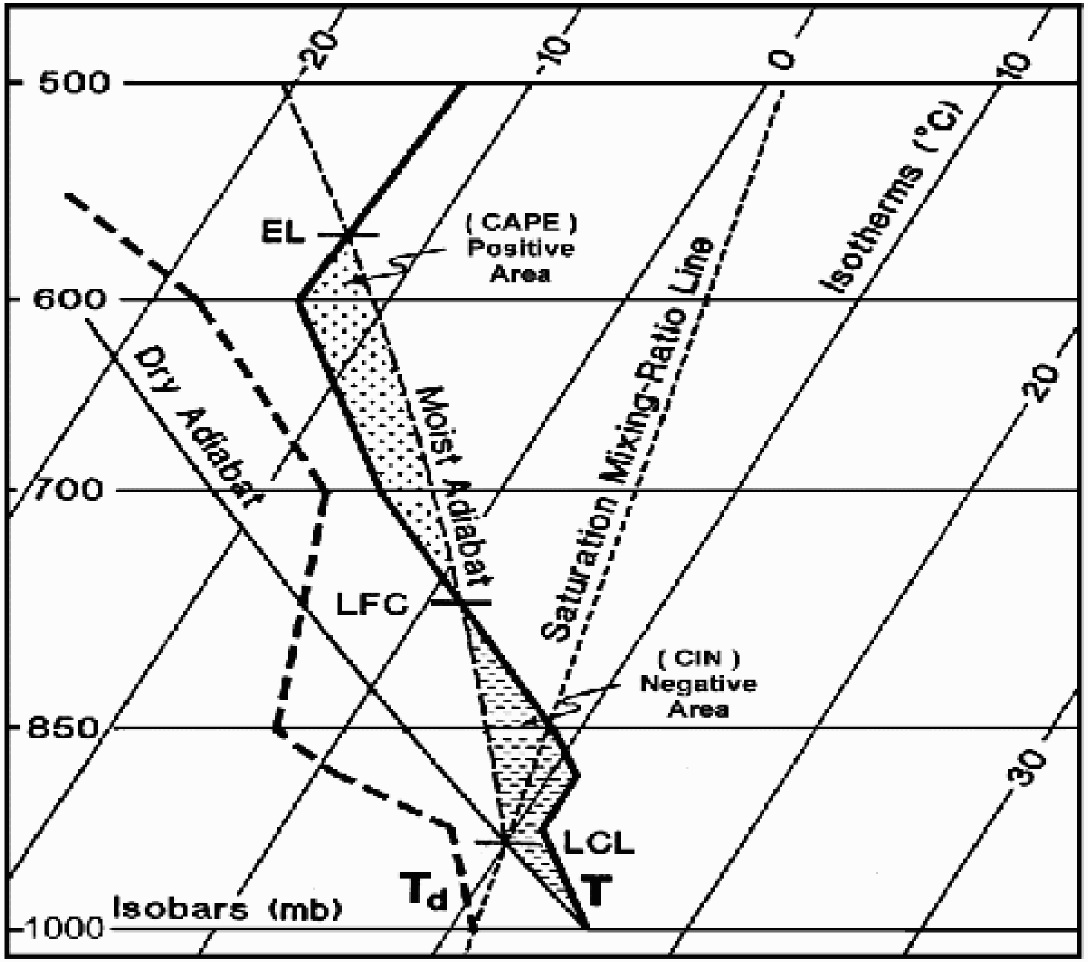


Figure 1. Showing the Positive (CAPE) and Negative (CIN) areas (from NWS/OSF/OTB, 1991).

Maximum Temperature

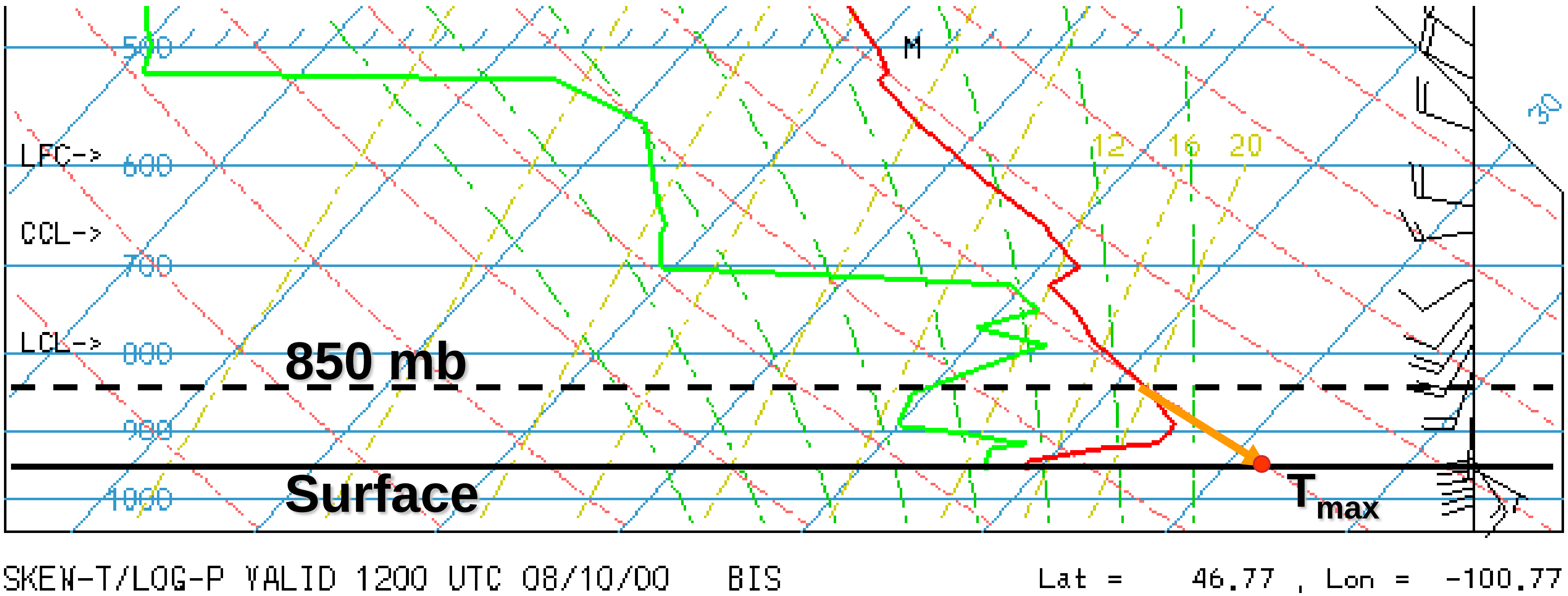
Assumes

- No significant temperature advection
- Strong winds not forecast

Maximum Temperature

Clear or Scattered Sky

- Solar Radiation Mixes Boundary Layer
- Follow the DRY adiabatic line from 850 hPa (mean PBL level) to the surface

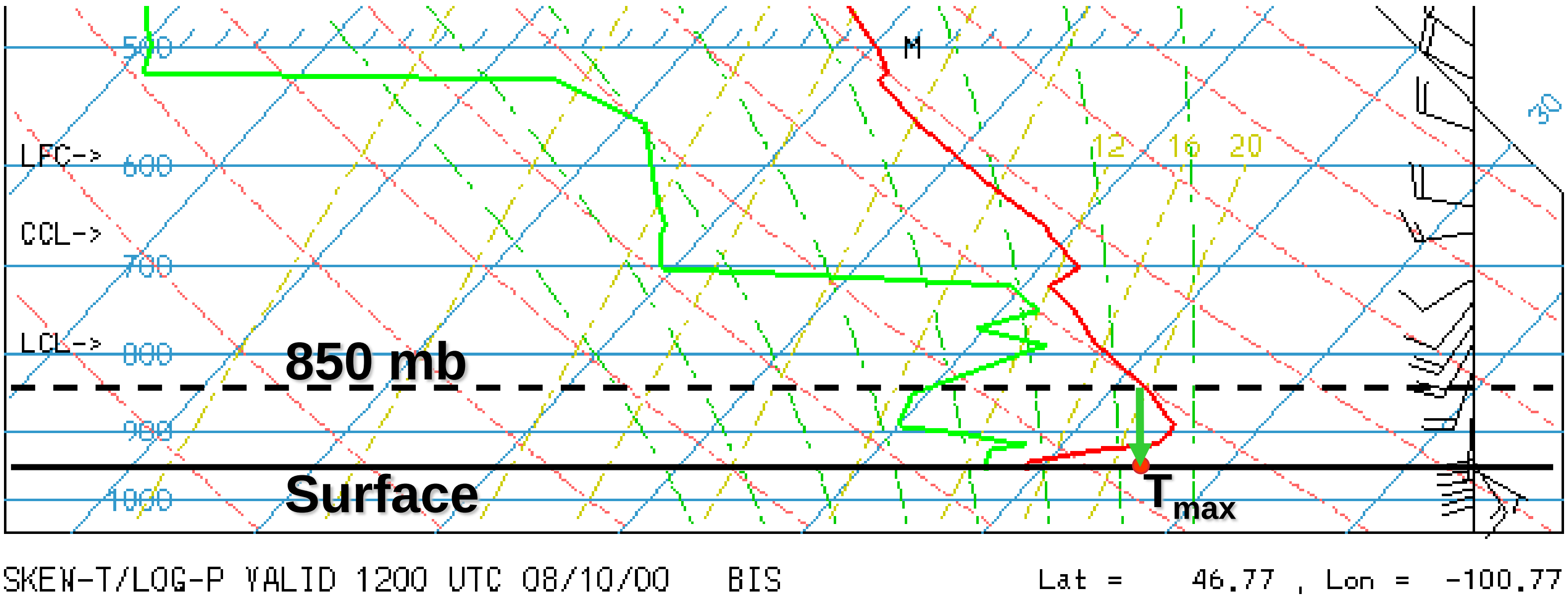


(courtesy F. Remer)

Maximum Temperature

Broken or Overcast Sky

- Mixing is much weaker
- Follow the pseudo-adiabat (moist adiabatic line) from 850 hPa to the surface

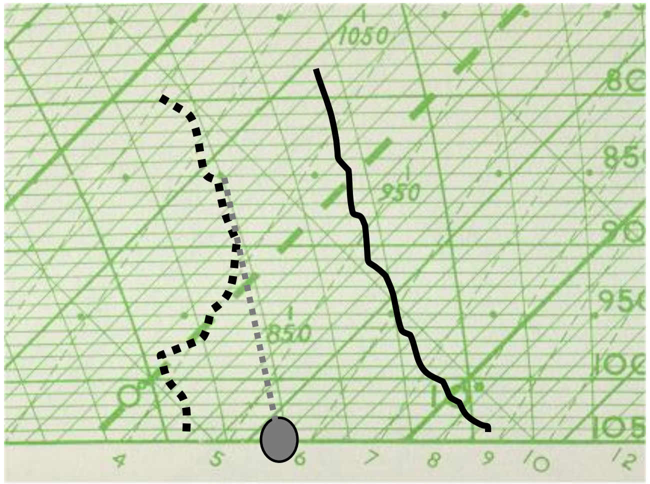


(courtesy F. Remer)

Minimum Temperature

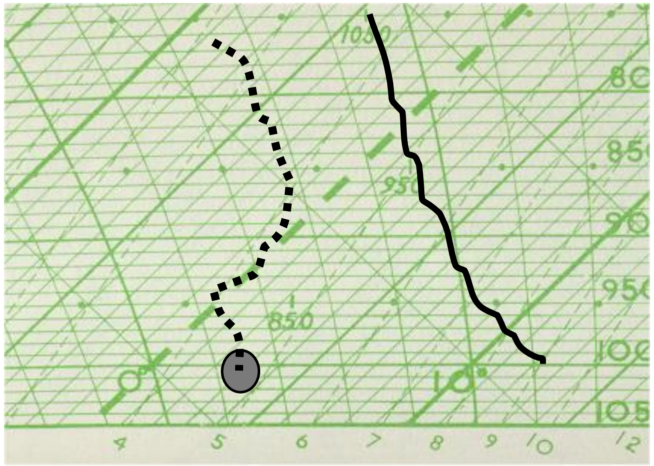
1st empirical method

Track the wet adiabat from T_d at 850 hPa to the surface



2nd empirical method

Find the T_d corresponding to T_{max}: that will be the next T_{min}



In both cases, the basic hypothesis is that air mass will not change