Atmospheric Stability/Skew-T Diagrams

Meteorology 311

Air Parcel

- Consider a parcel of infinitesimal dimensions that is:
- Thermally isolated from the environment so that its temperature changes adiabatically as it sinks or rises.
- Always at the same pressure as the environmental air at the same level, assumed to be in hydrostatic equilibrium.
- Moving slowly enough that its kinetic energy is a negligible fraction of its total energy.

Stability

- Stability describes how air parcels react to an initial vertical push by some external force.

- Forced to return to its original position: stable.

- Continues to accelerate away from its originial position without outside help: unstable.

- Continues to move away from its original position without accelerating: neutral.

Stability cont.

- Consider a small disturbance from equilibrium....
  - Note: Primed values refer to the PARCEL.

- $P = P'$

- Adiabatic, displacements on small time scales.

Lapse Rates

- Dry adiabatic lapse rate
  - Rate at which “dry” parcel changes temperature if raised or lowered in the atmosphere.
  - 10 °C/km
- Moist adiabatic lapse rate
  - Rate at which “moist” parcel changes temperature if raised or lowered in the atmosphere.
  - 6 °C/km
- Environmental lapse rate, Γ
  - Temperature structure of the environment.

Γ < Parcel Lapse rate

- Buoyant acceleration < 0.
- Buoyant force is opposite the displacement (negatively buoyant).
- Positive restoring force.
- Hydrostatically stable or positive stability.

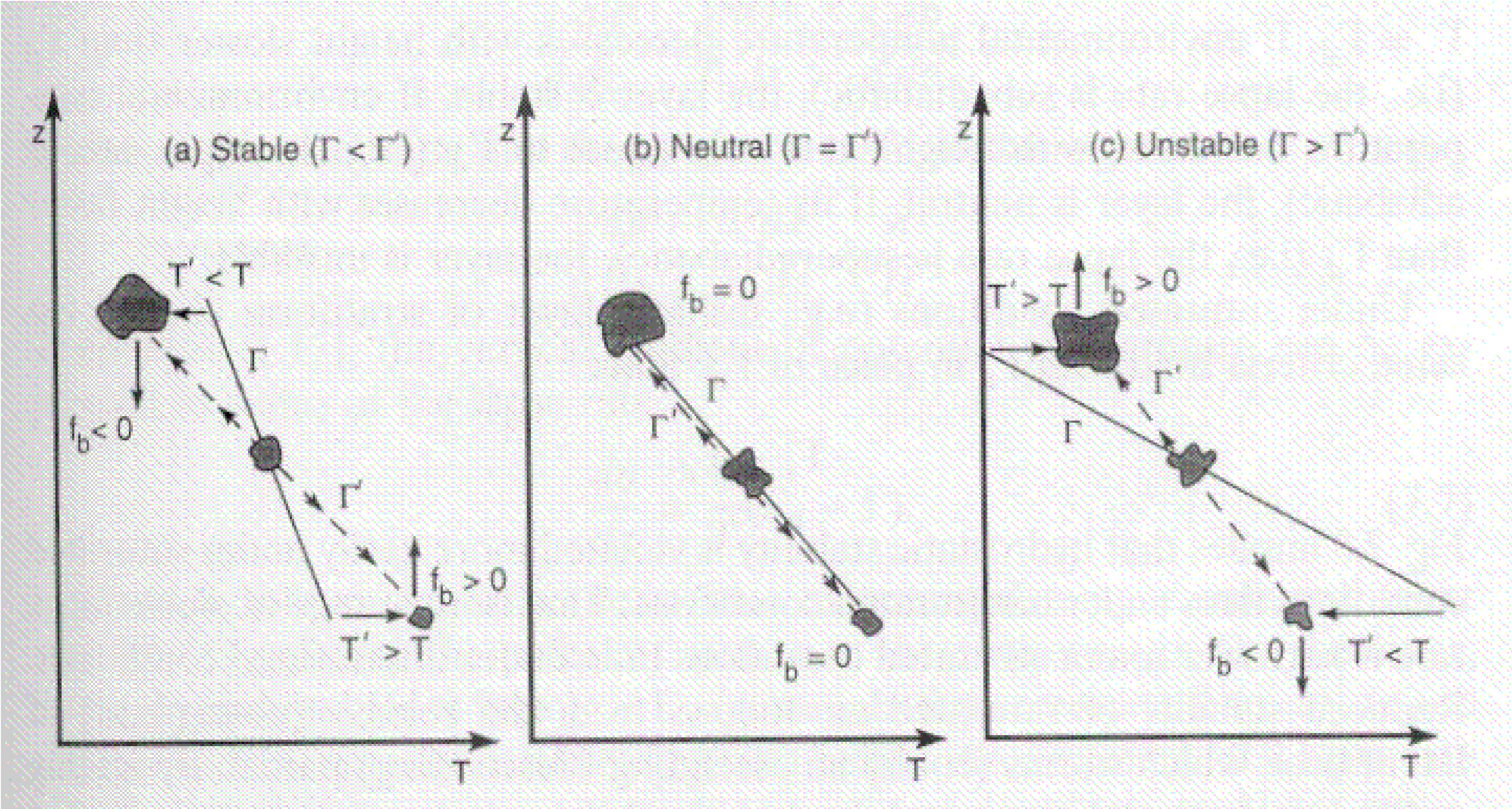
Γ = Parcel Lapse Rate

- Buoyant acceleration = 0.
- No restoring force.
- Displacements are met without opposition.
- Hydrostatically neutral or neutral stability.

$\Gamma >$ Parcel Lapse Rate

- Buoyant acceleration > 0
- Buoyant force in direction of displacement.
- Negative restoring force.
- Hydrostatically unstable or negative stability.

Stability - Visually



Stability – Visual cont.

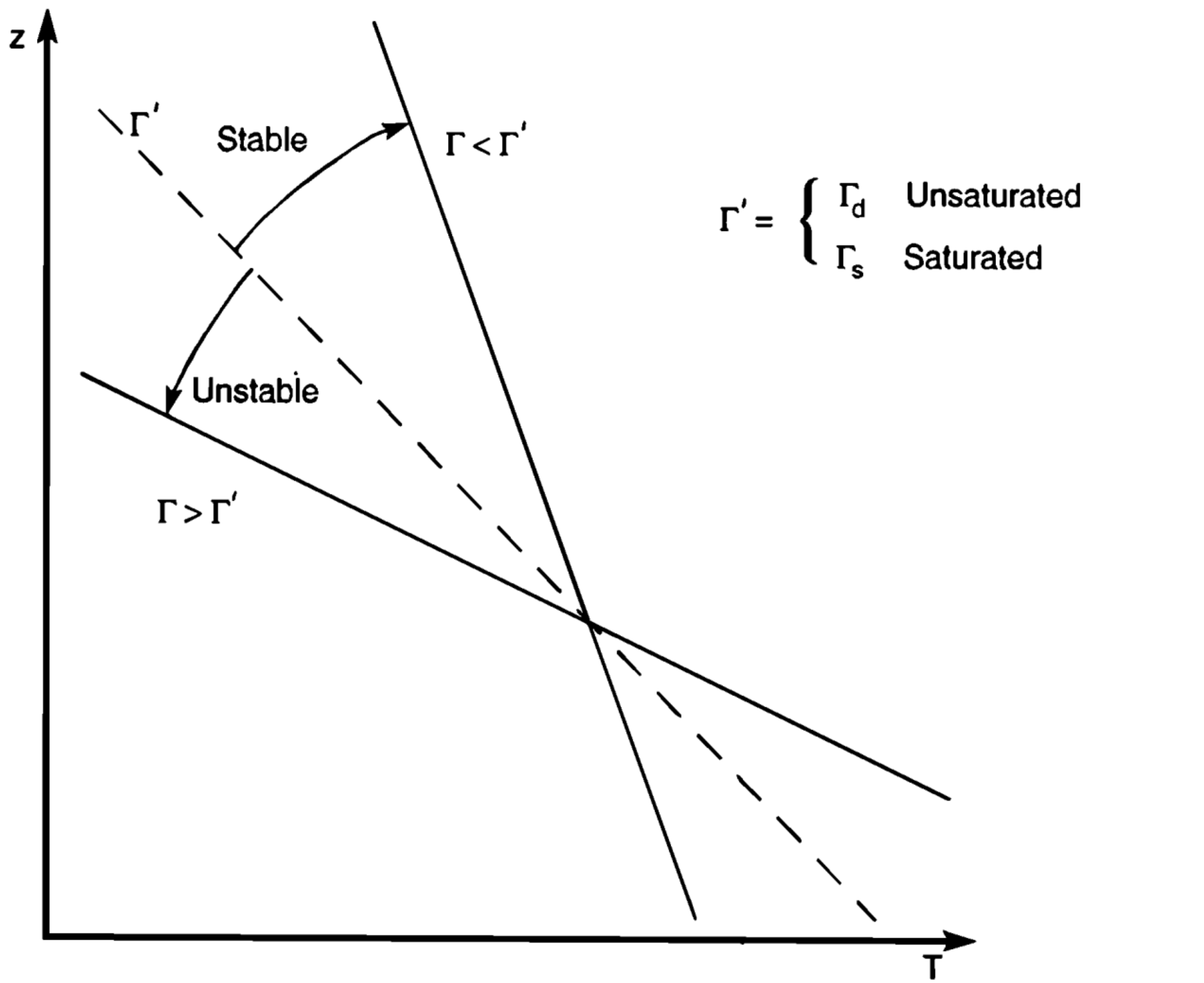


Figure 7.3 Vertical stability in terms of temperature and the environmental lapse rate Γ.

Stability - Theta

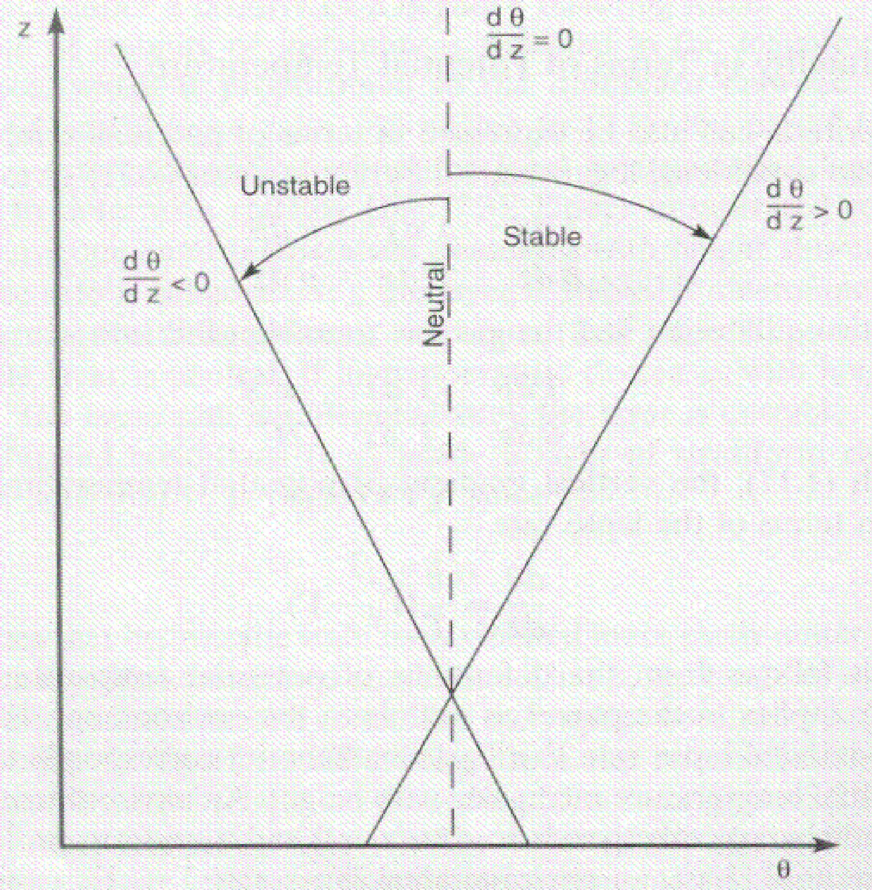


Figure 7.4 Vertical stability, under unsaturated conditions, in terms of potential temperatur

Moisture

- $\Gamma < \Gamma_m < \Gamma_d$
  - Absolutely stable.

- $\Gamma > \Gamma_d > \Gamma_m$
  - Absolutely unstable.

- $\Gamma_m < \Gamma < \Gamma_d$
  - Conditionally unstable.
  - Stable for unsaturated conditions.
  - Unstable for saturated conditions.

Conditional Stability

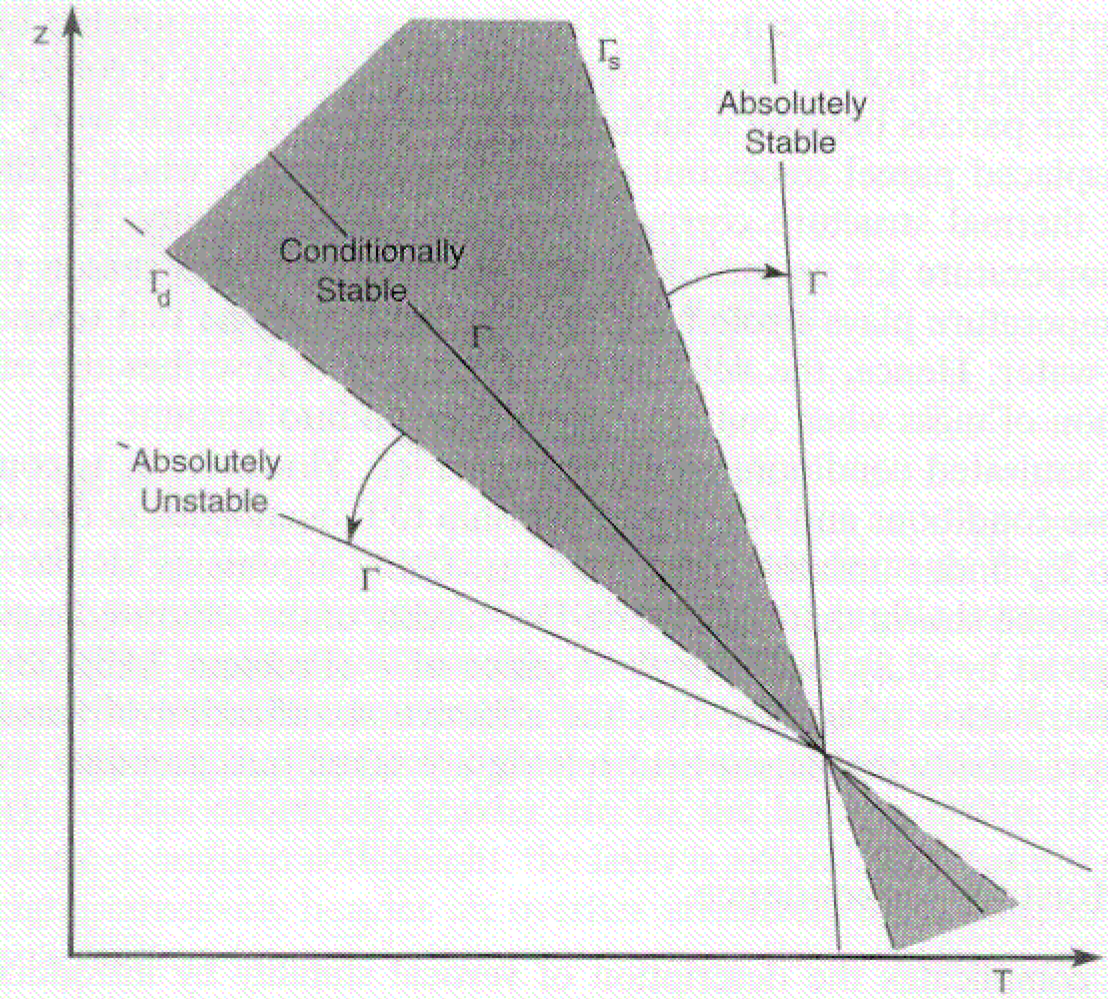


Figure 7.5 Vertical stability of moist air in terms of temperature and the environmental lapse rate Γ.

Vertical Motion

- Stability determines a layers ability to support vertical motion and transfer of heat, momentum, and constituents.

- How do you get vertical motion?
  - Frontal boundaries (airmass differences)
  - Topography
  - Convergence (continuity equation)
  - Differential heating

Changes in Lapse Rate

- Environmental Lapse Rate can change over time.
- Non-adiabatic heating and cooling
- Solid advection
- Differential advection
- Vertical motion

Thermodynamic Diagrams

- Let us plot the vertical structure of the atmosphere.
- Tephigram
- Stuve Diagram
  - Pseudo-adiabatic chart
- Skew-T, log P diagram
  - Most used operationally by forecasters.

Skew-T Diagram

- Y-Axis is logarithmic in pressure.
- Isotherms are “skewed” 45° from lower left to upper right.
- Dry adiabats: slope from upper left to lower right. Label in degrees Celcius.
- Saturation or “moist” adiabats – curved
- (green on official charts)
- Mixing ratio lines: dashed and slope a little from lower left to upper right (g/kg).

Movement

- If air is dry (not-saturated), θ is conserved.
  - Adiabatic, move along a dry adiabat or line of constant θ.
  - Mixing ratio does not change.
- If air is saturated, moisture condenses or evaporates, heat released impacts the temperature.
  - θ_e and θ_w keep the same value.
  - Mixing ratio changes.

Temperatures

- Potential temperature
  - Conserved in an adiabatic process
  - Dry adiabat
- Wet-bulb temperature
  - Conserved in a moist adiabatic process
  - Moist adiabat
- Equivalent potential temperature
  - Raise parcel until all moisture has condensed out and bring parcel back to 1000mb.
  - Used to compare parcels with different moisture contents and temperatures.

Important Variables

- Mixing ratio (w)
  - Use w line through T_d.
- Saturated mixing ratio (w_s).
  - Use w line through T.
- RH = 100% (w/w_s)
- Vapor pressure (e)
  - Go from T_d up isotherm to 622mb and read off mixing ratio in mb.
- Saturation vapor pressure
  - Use T, not T_d.

More Variables

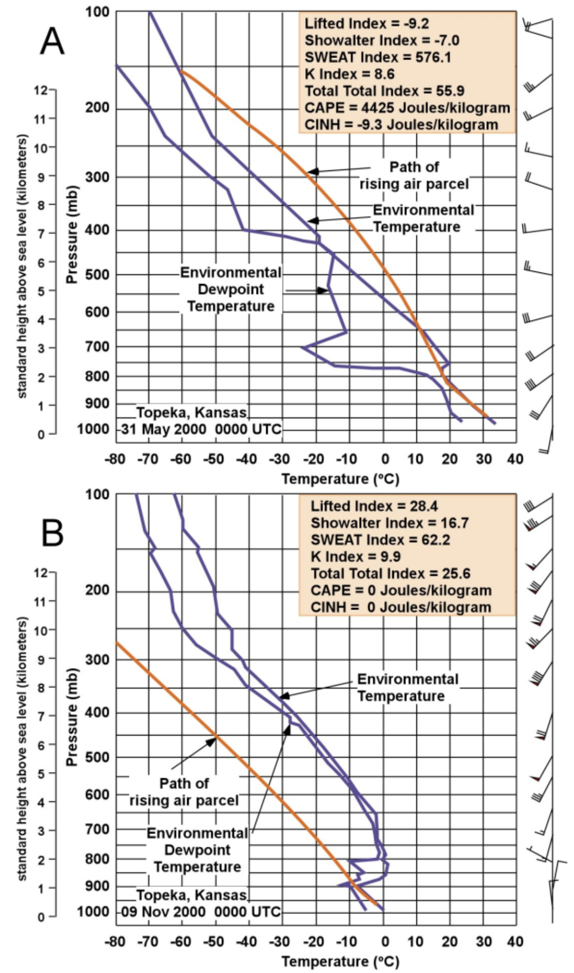
- Wet-bulb temperature (T_w).
- Wet-bulb potential temperature (θ_w).
- Equivalent temperature (T_e).
- Equivalent potential temperature (θ_e).

Important Levels

- LCL – lifting condensation level
  - Where lifted air becomes saturated.
- LFC – level of free convection
  - Where lifted air becomes positively buoyant.
- EL – Equilibrium level
  - Where lifted air becomes negatively buoyant up high.
- CCL – Convective condensation level.
  - Height to which a parcel of air would rise adiabatically to saturation from surface heating.

CAPE

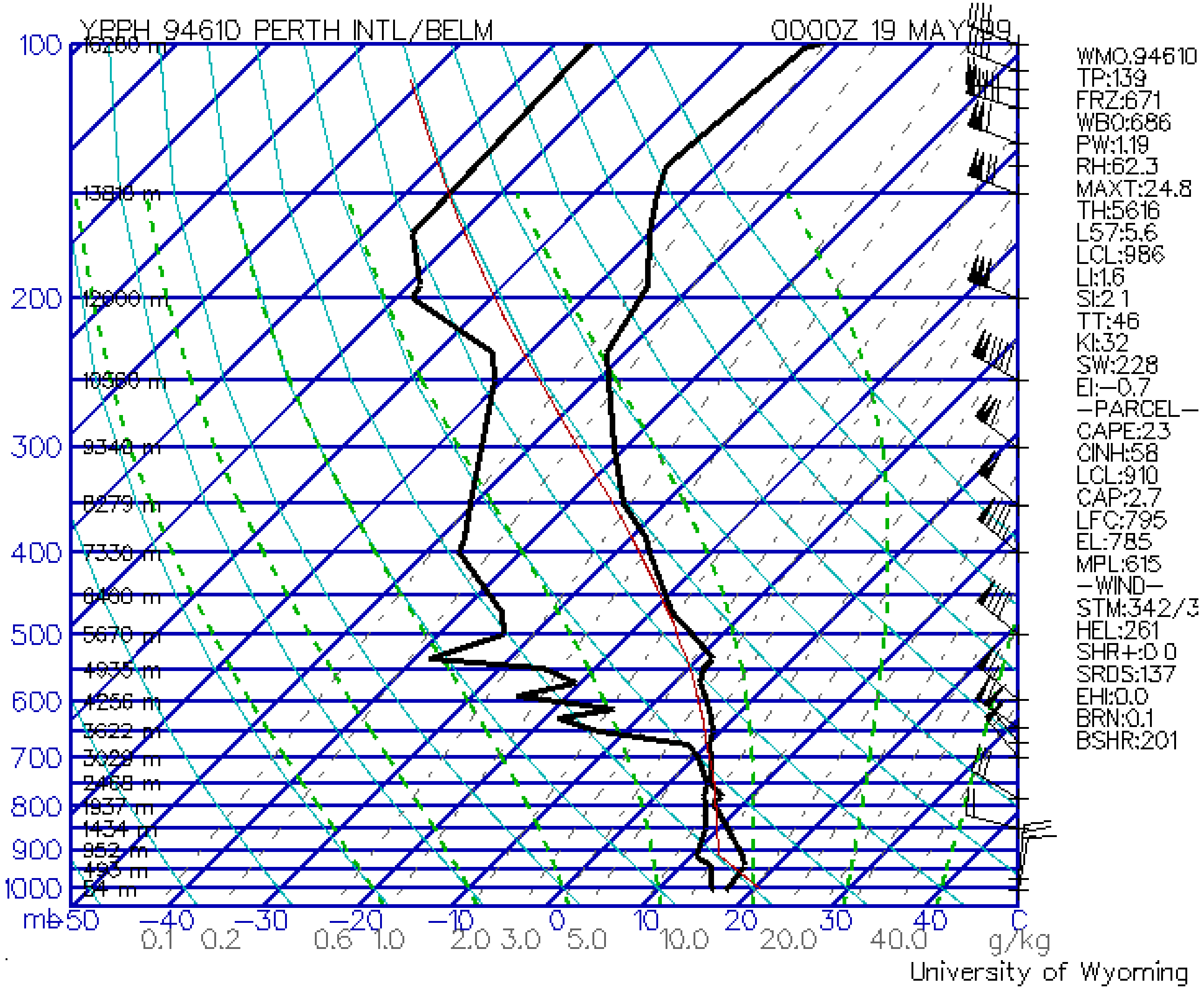
- CAPE = Convective Available Potential Energy
- Positive area between parcel path and environmental profile.
- Gives energy available to be converted to kinetic energy and upward motion.



Stability Indicies

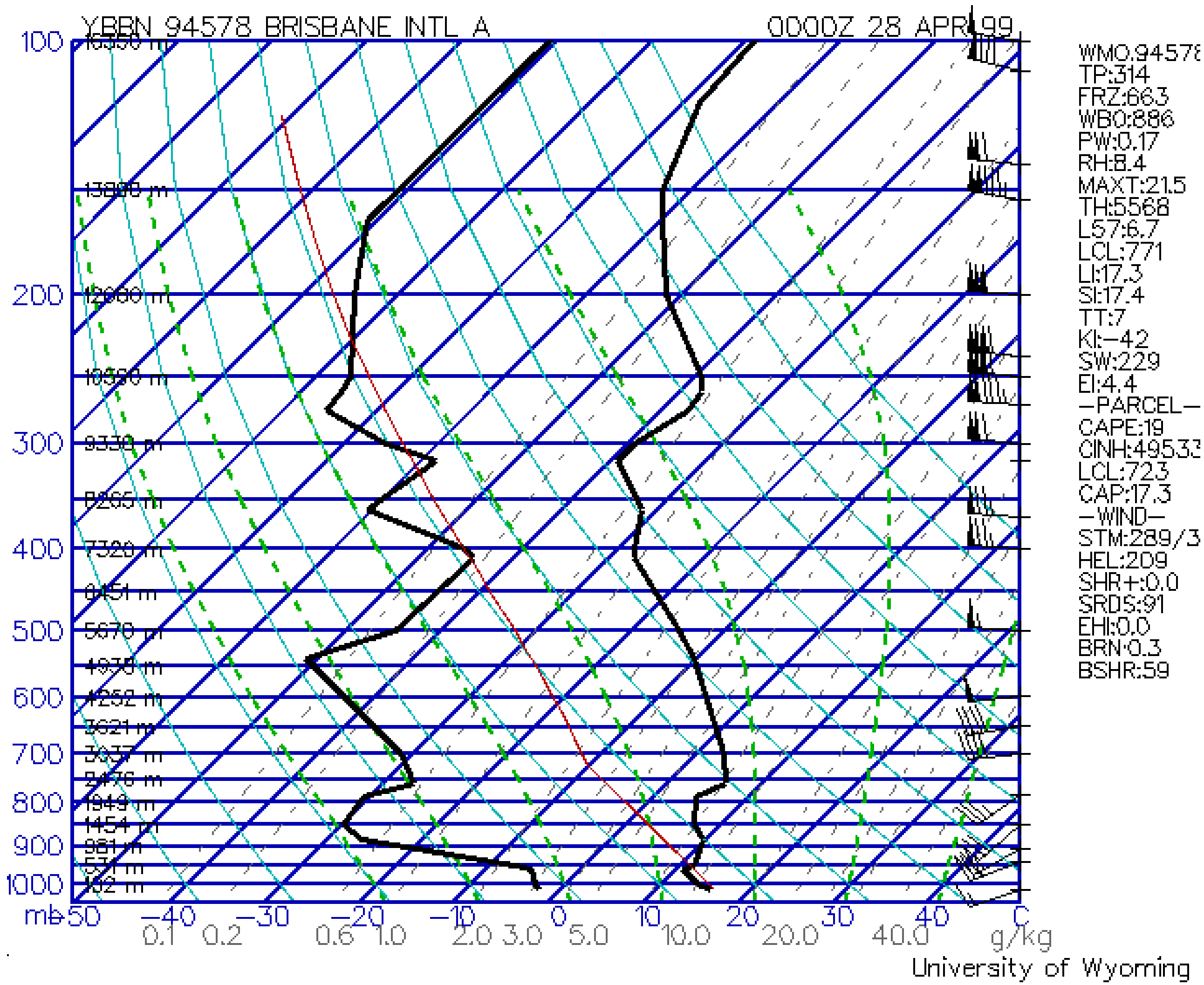
- LI – Lifted Index
- SI – Showalter Index
- K Index
- TT – Total totals
- SWEAT – Severe WEAT Threat index
- Precipitable water

Example #1

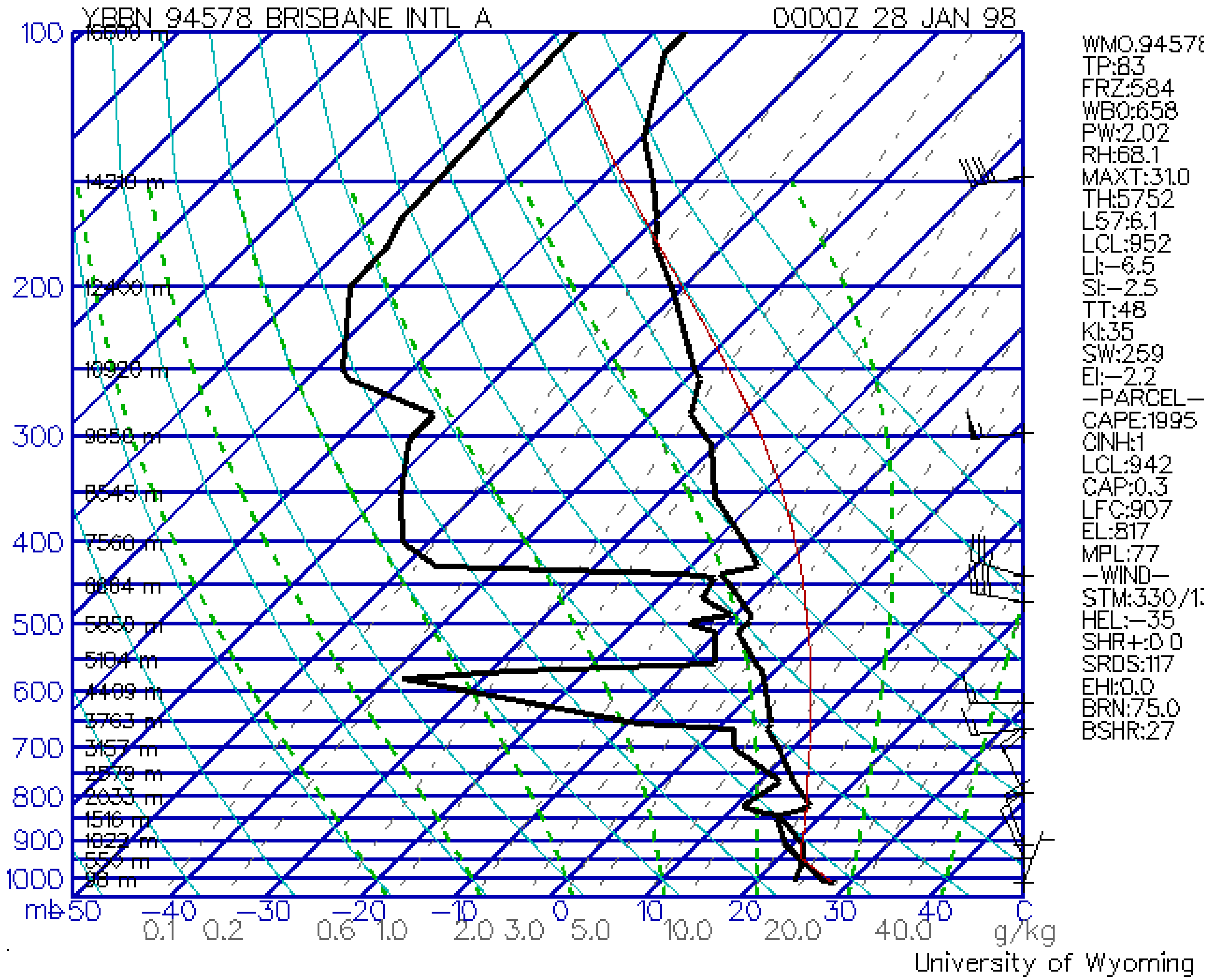


YPPH 94610 PERTH INTL/BELM
00Z 19 MAY 09
100
200
300
400
500
600
700
800
900
1000
mb
16200 m
13810 m
12000 m
10360 m
9340 m
8279 m
7330 m
6400 m
5670 m
4935 m
4256 m
3622 m
3029 m
2468 m
1937 m
1434 m
952 m
493 m
54 m
−50 −40 −30 −20 −10 0 10 20 30 40 C
0.1 0.2 0.6 1.0 2.0 3.0 5.0 10.0 20.0 40.0 g/kg
University of Wyoming
WMO:94610
TP:139
FRZ:671
WBO:686
PW:1.19
RH:62.3
MAXT:24.8
TH:5616
L57:5.6
LCL:986
LI:1.6
SI:2.1
TT:46
KI:32
SW:228
EI:−0.7
−PARCEL−
CAPE:23
CINH:58
LCL:910
CAP:2.7
LFC:795
EL:785
MPL:615
−WIND−
STM:342/3
HEL:261
SHR+:0.0
SRDS:137
EHI:0.0
BRN:0.1
BSHR:201

Example #2

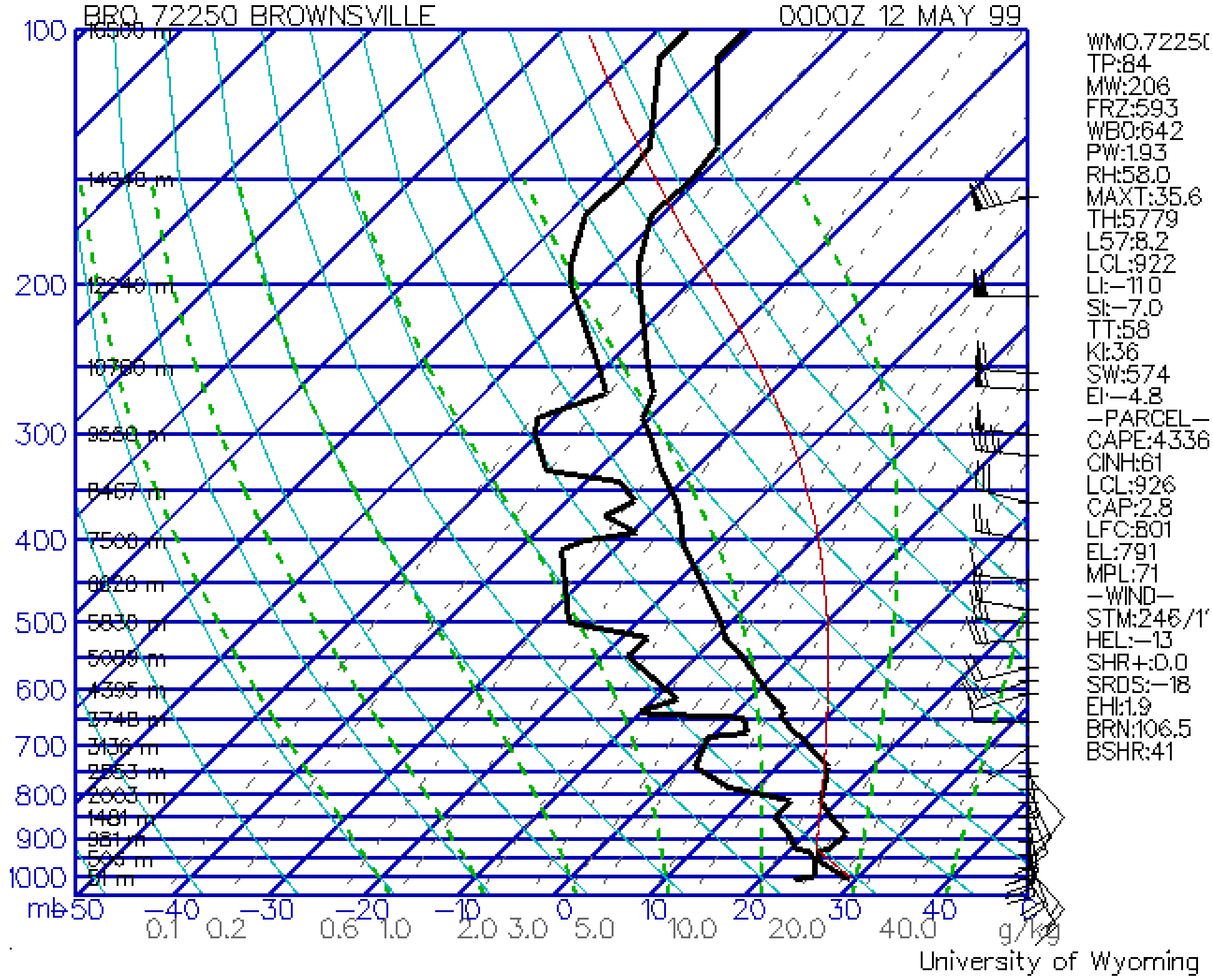

YBBN 94578 BRISBANE INTL A
0000Z 28 APR 99
100
200
300
400
500
600
700
800
900
1000
mb
−50 −40 −30 −20 −10 0 10 20 30 40 C
0.1 0.2 0.6 1.0 2.0 3.0 5.0 10.0 20.0 40.0 g/kg
University of Wyoming
WMO:94578
TP:314
FRZ:663
WBO:886
PW:0.17
RH:8.4
MAXT:21.5
TH:5568
L57:6.7
LCL:771
LI:17.3
SI:17.4
TT:7
KI:−42
SW:229
EI:4.4
−PARCEL−
CAPE:19
CINH:49533
LCL:723
CAP:17.3
−WIND−
STM:289/3
HEL:209
SHR+:0.0
SRDS:91
EHI:0.0
BRN:0.3
BSHR:59

Example #3



YBBN 94578 BRISBANE INTL A
0000Z 28 JAN 98
100
200
300
400
500
600
700
800
900
1000
mb
−50 −40 −30 −20 −10 0 10 20 30 40 C
0.1 0.2 0.6 1.0 2.0 3.0 5.0 10.0 20.0 40.0 g/kg
WMO:9457
TP:83
FRZ:584
WBO:658
PW:2.02
RH:68.1
MAXT:31.0
TH:5752
L57:6.1
LCL:952
LI:−6.5
SI:−2.5
TT:48
KI:35
SW:259
EI:−2.2
−PARCEL−
CAPE:1995
CINH:1
LCL:942
CAP:0.3
LFC:907
EL:817
MPL:77
−WIND−
STM:330/1
HEL:−35
SHR+:0.0
SRDS:117
EHI:0.0
BRN:75.0
BSHR:27
University of Wyoming

Example #4


BRO 72250 BROWNSVILLE
00OOZ 12 MAY 99
100
200
300
400
500
600
700
800
900
1000
mb
-50 -40 -30 -20 -10 0 10 20 30 40
0.1 0.2 0.6 1.0 2.0 3.0 5.0 10.0 20.0 40.0 g/kg
WMO.7225(
TP:84
MW:206
FRZ:593
WB0:642
PW:1.93
RH:58.0
MAXT:35.6
TH:5779
L57:8.2
LCL:922
LI:-11.0
SI:-7.0
TT:58
KI:36
SW:574
EI·-4.8
-PARCEL-
CAPE:4336
CINH:61
LCL:926
CAP:2.8
LFC:801
EL:791
MPL:71
-WIND-
STM:246/1'
HEL:-13
SHR+:0.0
SRDS:-18
EHI:1.9
BRN:106.5
BSHR:41
University of Wyoming